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Impact of palm oil sustainability certification on village well-being and poverty in Indonesia

Authors

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Competing interests

The authors declare no competing interest for this work.

Author contributions

T.S., M.J.S., E.M. and K.A.W. conceived the idea. T.S. designed the study, processed the socioeconomic and environmental data, and performed the analyses. M.J.S. coordinated the project, and obtained funding with E.M. and K.A.W. K.M.C. and H.G. provided the concessions data. E.A.L., F.A.V.S.J., C.L.M. and M.A. assisted with the socioeconomic and environmental datasets. T.S. and M.J.S. led the manuscript, which was critically reviewed and edited by the other authors. All authors contributed to the interpretation of analyses and gave final approval for publication.

Abstract

The Roundtable on Sustainable Palm Oil (RSPO) has emerged as the leading sustainability certification system to tackle socio-environmental issues associated with the oil palm industry. To date, the effectiveness of RSPO certification for achieving its socioeconomic objectives remains uncertain. We evaluate the impact of certification on village-level well-being across Indonesia by applying counterfactual analysis to multi-dimensional government poverty data. We compare poverty across 36,311 villages between 2000 and 2018, tracking changes from before oil palm plantations were first established to several years after plantations were certified. Certification was associated with reduced poverty in villages with primarily market-based livelihoods, but not with those in which subsistence livelihoods were dominant before switching to oil palm. We highlight the importance of baseline village livelihood systems in shaping local impacts of agricultural certification, and assert that oil palm certification in certain village contexts may require additional resources to ensure socioeconomic objectives are realised.

Main

Oil palm cultivation has expanded tremendously in response to global demand for oils and fats over the last three decades. In 2018, the crop covers around 19 million hectares of land across the tropics, and a further 10-14 million hectares is likely needed in this region to satisfy projected global demand in 2050[1]. In the same year, Indonesia was the world's largest palm oil producer, supplying more than 40 million tonnes of crude palm oil, or 56% of global production[2]. The country's oil palm plantation area has tripled since 2000 and now covers 14 million hectares, greater than the area of Java[2]. Unlike other key agricultural commodities in Indonesia where farms are largely managed by smallholders, the ownership of Indonesian oil palm plantations is mostly through private corporations[2] (Extended Data Figure 1).

The continuing expansion of oil palm across tropical countries has prompted fierce national and international debate[3,4]. While governments, industry lobbies, and companies have pointed to regional economic development and rural poverty alleviation to justify expansion of the oil palm sector[4-6], numerous social and environmental costs of the industry have also been reported. These include land conflicts[7-9], loss of forest[10], biodiversity[1] and traditional livelihoods and culture[8,11], water scarcity and pollution[12-14], increased flooding[15], and heightened risk of fire and concomitant emissions, especially due to expansion of plantations on peatland[16-19]. In response to these sustainability concerns, the Roundtable on Sustainable Palm Oil (RSPO) was formed in 2004 as a multi-stakeholder participatory body that promotes more sustainable production, in part by offering a sustainability certification system[20]. In 2019, around 4 million hectares of oil palm plantations had been certified, equating to ~20% of the global area cultivated[21]. Certified plantations are predominantly managed by companies (90%[21]), although there has been pressure on the RSPO to enable greater smallholder participation[22].

Despite 15 years of promoting more sustainable production practices, the effectiveness of RSPO certification in delivering social and environmental benefits to local communities in producing areas remains uncertain[23,24]. Mixed impacts of certification have been reported by several studies based on counterfactual evidence comparing the performance of certified and similar non-certified concessions[25-29]. Few if any such robust evaluations have addressed social aspects beyond basic financial measures, mainly because of a lack of systematic socioeconomic data availability over large spatial and temporal scales. In addition, past social evaluations have not fully accounted for the substantial heterogeneity in baseline village conditions, such as socioeconomic and sociocultural characteristics, which may result in misleading assessments of certification outcomes[30,31]. Indeed, numerous sociology and development studies provide evidence for the widespread

85 failures of development programmes based on modernization approaches and technologies applied to
86 agriculture without adequately considering resource barriers to local communities, institutional and
87 infrastructural constraints, and cultural values[32,33] (see Supplementary Methods 1 for further discussion).

88 Here we evaluate the impact of RSPO certification on village well-being across the main oil palm
89 producing regions of Indonesia: Sumatra (land area of 470,000 km^2; comprising 24,259 villages or *Desa*),
90 Kalimantan (540,000 km^2; 7,095 villages), and Papua (420,000 km^2; 4,957 villages) (Figure 1). Of the total
91 36,311 villages sampled across the three islands, we identified 2,602 villages with large-scale non-certified oil
92 palm plantations (i.e. those with at least 10% of the land area allocated to non-certified industrial plantations –
93 the median amount across the whole region) and 794 villages with large-scale RSPO-certified plantations (i.e.
94 ≥10% of the village land area allocated to RSPO-certified plantations). We define village-level well-being in
95 line with the Sustainable Livelihood Approach[34-35] in terms of the socioeconomic (i.e., living conditions,
96 infrastructure, and income support) and socioecological (i.e., security, social equity, and natural hazard
97 prevention) capabilities of people to function in society (Supplementary Table 1 and Supplementary Methods
98 2). Poverty arises when these capabilities break down[36]. We applied rigorous counterfactual analysis based
99 on statistical matching methods to address three research questions: (1) How have oil palm and RSPO
100 certification expanded in Indonesia in the context of ongoing rural development and agrarian transition?; (2)
101 What have been the impacts of oil palm and subsequent RSPO certification on village-level well-being?; and
102 (3) What lessons can be learned from how these impacts have been generated in relation to changing land-
103 use, livelihoods, and community composition?

104 To answer these questions, we tracked changes in 18 socioeconomic and socioecological well-being
105 indicators throughout the certification process, starting before plantations were first established to several
106 years after plantations were certified. We derived these well-being indicators together with information on
107 primary livelihood sectors from a large longitudinal dataset of village-level censuses - *Potensi Desa* (PODES)
108 or 'Village Potential' - collected by Indonesia's Bureau of Statistics (BPS) roughly every three years between
109 2000 and 2018[37]. By incorporating the latest census in 2018, we evaluated poverty change in 587 villages 5-
110 11 years after the development of industrial oil palm plantations and 500 villages 5-11 years after the
111 issuance of RSPO oil palm certificates, thereby providing insights on how impacts manifest as land is first
112 converted to oil palm and then later certified. This nuanced assessment of how the characteristics of the oil
113 palm industry evolve over time in a particular location is rarely addressed in other studies.

114 Regional variation in oil palm and RSPO certification

115 The pace of development in Indonesia's oil palm industry has been unevenly distributed. Most development
116 has occurred in Sumatra (now 81,200 km^2) (Figure 1a and Extended Data Figure 2), with the island being the
117 oldest centre of oil palm production. The industry then expanded eastward across the major regions of
118 Kalimantan (53,300 km^2) (Figure 1b and Extended Data Figure 3) and more recently Papua (2,100 km^2)
119 (Figure 1c and Extended Data Figure 4). In Sumatra, the extent of oil palm plantations nearly doubled since
120 2000, while Kalimantan and Papua experienced a near-fourfold increase in production area over the same
121 period (Figure 1 and Extended Data Figures 2-4). The three regions can be viewed as being at advanced,
122 intermediate, and early stages of oil palm development, respectively. These distinct development stages are
123 broadly reflective of the expansion of the crop pan-tropically. For example, Malaysia and Thailand are also at
124 an advanced stage of oil palm development, while the industry is still in its infancy across Latin America[1].

125 The developmental context in Sumatra, Kalimantan, and Papua is also reflected in patterns of
126 plantation ownership. In Indonesia, cultivation of more than 25 hectares of croplands by a single farmer or
127 entity requires a concession permit (*Izin Usaha Perkebunan* or IUP), issued by the head of a regency, mayor,
128 or governor (Ministerial Decree No. 98/Permentan/2013). In Sumatra, between 2000 and 2018, oil palm
129 plantations (i.e. planted oil palm) are largely dominated by non-concession holders (64% for NCONC), which
130 mostly represent smallholders (68%) and medium to large-scale industrial plantations with unknown
131 concession status (32%, Supplementary Figure 1). There, the rate of plantation expansion outside of known
132 concession boundaries (NCONC) has exceeded that within large-scale concessions, i.e., non-certified
133 industrial oil palm plantations (CONC) and RSPO-certified industrial plantations (CERT) (Figure 1a and
134 Extended Data Figure 2). Conversely, over the same period, large-scale industrial plantations have
135 dominated oil palm expansion in Kalimantan and Papua (66% for CONC and CERT combined in Kalimantan
136 and 69% for CONC in Papua) (Figures 1b-c and Extended Data Figures 3-4).

137 Analysis of the primary land-use or cover in villages between 2000 and 2018 indicates that those with
138 ≥10% of village land area under industrial oil palm plantation in 2018 but <10% of area in industrial oil palm in
139 2000 experienced a typical sequence of land-use prior to oil palm development (Figure 2a and Extended
140 Data Figure 5). In 2000, 23% of these villages were primarily forested, and timber was frequently
141 commercially harvested[38] resulting in degraded forest stands. These villages were then transformed to
142 agricultural lands, mixed plantations and shrubs, then to (non-certified) industrial oil palm plantations. Some
143 of the existing (non-certified) oil palm plantations were later granted RSPO certification. Conversion from
144 forest to certified plantations had rarely occurred (Extended Data Figure 5).

Each of these land-uses is associated with specific livelihood systems and community composition (i.e. ethnicity) within village boundaries defined in the PODES census. Based on data from 2000, 2005, 2011 and 2018 across villages in Sumatra, Kalimantan, and Papua, those villages with high natural forest cover were typically dominated by subsistence-based communities (i.e. subsistence farming, fishing, and forest product gathering, in complex agroforestry systems and with weak exposure to the market economy) and comprised a high proportion of people belonging to ethnic groups native to the island (Figure 3). Villages with agricultural lands, mixed plantations and shrubs as the primary land-use or cover typically had a larger proportion of agricultural plantation communities, mainly polyculture smallholders (with some exposure to the market system[30,31]), and larger proportions of ethnic groups from other islands who are likely recent migrants (Figure 3). Villages with non-certified oil palm plantations as the primary land-use had substantially larger proportions of their community working in plantation agriculture, where monoculture oil palm was the norm (with stronger market-driven orientation[30,31]), and large proportions of migrants (Figure 3). In villages dominated by the RSPO-certified plantations, monoculture oil palm plantation communities and migrants were also prominent (Figure 3). Thus, primary land-use transition is likely to have significant social implications for village communities through changes in livelihood systems and social structure (Figure 2b). These transitions are not necessarily unidirectional; for example, if oil palm fails, the system can return to mixed plantations and shrubs. We do not consider such transitions away from oil palm here.

Rural development has traditionally been, and often still is, pushed by governments to achieve development targets measured mostly through economic material attainment (i.e. large industry and manufacturing, and the market-based economy), rather than on improving underlying human-capital (i.e. capability and adaptation of technology within local culture, knowledge, and outlook)[39]. Relying heavily on industry and market-driven systems to meet development targets can result in immense social costs to rural communities because doing so allows little opportunity and time for people to adapt[40]. Kalimantan exemplifies this type of rapid development over the last two decades, as evident from the high prevalence (52%) of villages experiencing drastic change in dominant land-use from high natural forest cover to primarily oil palm monoculture (41%) and from forest to certified plantations (11%) between 2000 and 2018 (Figure 4a). Comparatively, in Sumatra and Papua 88% of villages with industrial oil palm plantations or certified plantations as the primary land-use in 2018 were already dominated by industrial monoculture plantations in 2000 (Figure 4a).

Land-use changes in villages shifting to industrial oil palm plantations (Figure 4a) reflect an underlying pattern of oil palm development and expansion in Indonesia. Papua represents an early stage of

the oil palm industry, where plantation development is mainly confined within former or current transmigration villages and operated mostly by large oil palm companies[41] (Figure 4a and Extended Data Figure 4). Kalimantan represents the intermediate stage of industrial oil palm development, where company plantations have expanded rapidly into villages in forested landscapes that are dominated by subsistence-based communities (Figure 4a and Extended Data Figure 3). These expansions lead to an influx of workers and stimulate spontaneous migrations to the newly opened oil palm areas [42]. At this intermediate stage, oil palm smallholdings also expand, but the expansion rate is slower than the industrial-scale plantations (Extended Data Figure 3). Sumatra represents the advanced stage of oil palm development, where the number of smallholders, who either migrated in the preceding intermediate stage or more recently, continues to grow and expand exceeding the rate of expansion of the company plantations (Figure 4a and Extended Data Figure 2). This in turn creates a complex company and smallholder relationship[43,44]. The intermediate stage of oil palm development that occurred over the last two decades in Kalimantan (Figure 4b) generated swift radical transformation in village life systems in many parts of the island which often led to conflict[30,31]. Based on the PODES data, during this transformation period, social conflicts were 22% more prevalent in villages with industrial oil palm plantation development compared to those without, and such conflicts were more prevalent in Kalimantan than in Sumatra and Papua (Supplementary Figure 2).

Impacts of oil palm and certification on well-being

We assessed the impact of RSPO certification on village well-being by comparing the change in equally-weighted indicators in villages with plantations certified for 5-11 years to those with non-certified plantations over the same time interval, while ensuring similar baseline characteristics in both types of villages (Supplementary Table 2). Results aggregated across the three Indonesian islands indicate that the impact of certification varied by baseline village primary livelihood sector prior to certification. Compared to similar villages with non-certified plantations, those with certified plantations experienced an overall reduction in well-being. Combined measures of socioeconomic and socioecological well-being declined by 11% on average in communities that relied on subsistence-based livelihoods prior to certification compared to non-certified villages (Figure 5b). This decline was driven mainly by the fall in socioecological indicators, predominantly via a significant increase in the prevalence of conflicts, low wage agricultural labourers, and water and air pollution (Extended Data Figure 6). Conversely, the overall well-being marginally improved by 4% in communities that relied on market-based livelihoods before certification (i.e. polyculture plantations or monoculture non-certified oil palm plantations) (Figure 5b).

We found that expansion of oil palm into new areas resulted in similar well-being change patterns as certification (Figure 5). Villages that relied on subsistence livelihoods prior to oil palm development experienced an overall reduction in well-being by 16% on average after 5-11 years compared to the counterfactual of no oil palm development across all three islands (Figure 5a). The reduction in overall well-being was driven by the decline in both socioeconomic and socioecological components, primarily the reduction in electricity access, adequate sanitation and cooking energy, and secondary schools, as well as the increased prevalence of conflicts, low wage agricultural labourers, water pollution, and floods (Extended Data Figure 7). Villages with oil palm plantations where the majority of communities had relied on market-based livelihoods before oil palm development (i.e. polyculture plantations outside concessions) also experienced reduced overall well-being by 9% compared to the counterfactual, but the impact on socioeconomic well-being was marginally positive (improved by 3% on average) (Figure 5a). Thus, the immediate impact of oil palm development in the production villages with market-based livelihoods appears to be better than that observed in villages dominated by subsistence-based livelihoods; socioecological losses appear to be partially compensated by socioeconomic gains.

Because in Kalimantan certification has taken place disproportionately in areas where village communities were still dependent on subsistence-based livelihoods (Figure 4a), the impact of certification on well-being in this region has been negative overall (Extended Data Figure 8b). On the other hand, the impact of certification in Sumatra has been positive overall (albeit marginal) (Extended Data Figure 8b), mitigating negative impacts on socioecological well-being indicators associated with non-certified oil palm. Unlike in Kalimantan, a higher proportion of plantations in Sumatra has been certified in villages where market-based communities are more dominant (Figure 4a). This demonstrates that failing to account for the influence of baseline livelihoods on the potential benefit flows of certification could lead to misplaced inferences from the impact evaluation.

Well-being change through oil palm and certification processes

Trends in the change of village well-being through the process of oil palm expansion and certification provide a more comprehensive picture of the underlying mechanisms driving the impact (Figure 6). In villages with subsistence livelihoods, socioeconomic improvements in oil palm villages were slightly slower to accumulate than those in non-oil palm villages, but this trend improved marginally following RSPO certification. Socioecological well-being in these subsistence-based villages worsened following oil palm development, a trend that continued after certification (Figure 6a). This pattern was widespread in Kalimantan (Extended Data

Figure 8b), particularly in lowland peatland areas near the coast, which have experienced most certification efforts to date. Conversely, improvements to socioeconomic well-being experienced in Indonesia were greater where oil palm, and later certification, was established in villages with market-based livelihoods. Measures of socioecological well-being in these market-based villages deteriorated following expansion of the oil palm sector, but later improved following certification, albeit marginally (Figure 6b). Thus, socioecological well-being in market-based villages with certification at the current state is indeed worse than without oil palm development two decades ago, but slightly better than the counterfactual of no certification a decade ago. This pattern is prevalent in Sumatra (Extended Data Figure 8b). Thus, focusing merely on the immediate effect of certification could lead to missed crucial information and insights about what happened in village communities before certification even existed.

The overall negative association between certification in subsistence-based villages and outcome variables (compared to a counterfactual of non-certified plantations) reflects not an adverse outcome from certification itself, but the overwhelming social impact of large-scale industrial oil palm plantations on the well-being of communities who still depend on forest and associated natural capital, which indeed may be difficult to compensate even within a sound regulatory certification framework. In Indonesia, the size of individual RSPO-certified plantations is significantly larger than non-certified industrial plantations (i.e. median plantations area of 8,000 and 2,500 ha for certified and non-certified plantations, respectively, based on data from Sumatra and Kalimantan) (Extended Data Figure 9a). A certified plantation company typically manages 10% of village land areas across three adjoining villages (Extended Data Figure 9b). Comparatively, one non-certified industrial plantation company typically manages only 3% of a village land area (Extended Data Figure 9b). These differences are likely related to the high costs and technical capacities required for the RSPO membership participation and further for certification, which only large companies can bear[45]. This implies that there is likely an immense pressure being placed on the environment (i.e. soil, air, and water quality and quantity) by certified plantations and the associated mills relative to non-certified ones simply due to the total plantation size and production scale across broader landscapes comprising several neighbouring villages[29,46,47]. Further, the scale of certified plantations compared to the non-certified ones indicates that the certified companies tend to have a much larger influence over village land-use, environment, and economy compared to those managing non-certified plantations. This could create more unbalanced social power structures in certified plantations in which traditional communities and their local governance have a relatively limited say over what happens on their land[40]. Thus, although here we have carefully controlled for the total size of all industrial plantations at village-level in order to fairly compare certified versus non-certified

plantation villages (Supplementary Table 2), the effect observed in certified plantation villages is likely to be masked by the overall plantation impact over larger jurisdictional scales. This suggests that the amount of land under cultivation by a single entity has significant implications for the extent to which the perceived benefits of certification translate to improvements in community well-being. Our findings for the subsistence villages also imply that similar negative implications for community well-being recorded for certified plantations will likely occur for similarly extensive non-certified plantations.

Conclusion

The effectiveness of RSPO certification in upholding social and environmental standards within the oil palm industry has been called into question[23,24]. Using a comprehensive counterfactual assessment of longitudinal census data from Indonesia, the world's leading palm oil producing country, we show that the association between RSPO certification and village-level well-being varies by location and baseline village livelihood conditions before certification was initiated. While marginal positive impacts were observed in villages where most communities relied on market-based livelihoods prior to certification, RSPO certification was associated with largely negative outcomes in rural villages oriented toward subsistence agriculture. The latter was likely because certified plantations under single companies tend to be substantially larger than non-certified plantations and cover several neighbouring villages. As a result social and environmental externalities are difficult to remediate.

A potential caveat to these findings is that our analysis specifically focuses on the direct impact of certification and oil palm development on villages with oil palm production. We did not assess the possibility that impacts of oil palm or certification may be spatially autocorrelated or could lead to spillover effects[29] over a broader extent beyond the production areas, e.g. in neighbouring villages without the oil palm industry. If this kind of spill-over mechanism exists, the oil palm industry could even generate a wider welfare gap among villages at broader jurisdictional scales (e.g. regency level) by accruing socioeconomic and socioecological costs to rural subsistence-based villages with the oil palm industry while accumulating most of welfare benefits to suburban market-based villages. We also did not assess how different categories of oil palm production (i.e. different types of smallholders such as independent versus tied smallholders, and non-certified plantations) within villages classified as certified may have contributed to well-being, since data are not currently resolved to these levels. Our evaluation focuses on localised impacts collectively over large spatial scales but does not incorporate national-level socioeconomic benefits obtained through taxation of palm oil production. Additional indirect impacts of the RSPO on government sustainability policies and

297 practices for oil palm, such as the development of the national Indonesian Sustainable Palm Oil (ISPO)
298 certification standard, are also so far immeasurable. These potential caveats notwithstanding, our appraisal
299 has established important baseline information for further impacts to be monitored as the RSPO standard
300 develops.

301 Our finding that oil palm development has failed to improve well-being in rural subsistence villages
302 calls for careful consideration by key decision-makers of unintended indirect impacts of pushing large-scale
303 industrial oil palm into frontier forest areas where local communities still rely heavily on environmental
304 services. We feel that it is important for governments in oil palm producing countries to consider limiting the
305 extent of industrial-scale plantations that can be developed until more positive impacts on community well-
306 being can be guaranteed. This not only applies to existing rural areas in Indonesia, but also to other world
307 regions such as Central and West Africa and Latin America where the oil palm industry is expanding. RSPO's
308 recent commitment to zero-deforestation and avoidance of peatlands[20] as well as Indonesia's moratorium on
309 concession allocation in primary forests and on peatlands should help steer the industry towards already
310 developed agricultural lands with primarily market-based livelihoods.

311 Given that challenges associated with the oil palm industry vary by village baseline primary
312 livelihoods, specific targeting of these livelihoods in certification criteria, as well as ensuring compliance with
313 existing criteria with respect to livelihoods and communities, is recommended. In rural subsistence villages
314 where industrial plantations have been established, we recommend further scrutiny by certification assessors
315 on stringent compliance of social and environmental measures by companies - not only on zero deforestation,
316 but also on preventing and mitigating pollution and water scarcity, and the avoidance of plantation expansion
317 without Free, Prior and Informed Consent, as defined in the RSPO Principles and Criteria. In market-based
318 villages, in addition to the aforementioned activities, the RSPO should continue focusing on supporting
319 smallholder participation and encouraging company-smallholder cooperation. The RSPO jurisdictional
320 approach to certification[22] has recently been piloted in several former transmigration villages, e.g. in Seruyan
321 Regency in Central Kalimantan, and holds great promise for these market-based villages in supporting
322 "shared responsibilities" and cooperation across multiple stakeholders to work together towards improving
323 sustainability at village jurisdictional levels.

324 # Methods

325 ## Data

Oil palm plantations and certification and land cover

Throughout, the term `plantation´ refers to the area planted with oil palm, and `concession´ the area where a land permit has been granted to develop oil palm, but where the land has not necessarily been planted. Therefore, a concession owned by a company can either cover a larger area than the plantation if the concession is not fully developed, or cover roughly the same area as the plantation if the concession is entirely planted with palm. A plantation can also be developed outside a company concession, either as a smallholding or illegally[43].

We used plantation maps of every three years between 1997 and 2014, described in Santika *et al.* [30,31], but extended to 2018 and to cover Sumatra and Papua. These include medium and large-scale industrial plantations (25-100 ha and >100 ha, respectively) and smallholder plots (<25 ha). We also used spatial data on oil palm concessions and RSPO member plantations (certified and non-certified) across Indonesia described in Carlson *et al.*[26]. The data contain concessions certified by 2015, which we updated to include those certified or proposed for certification between 2015 and 2018 through web searching of records of RSPO-certified mills and supply estates. Annual forest cover 2001-2018 was estimated by overlaying the extent of natural forest (primary and secondary) across Indonesia in 2000 provided by Margono *et al.*[48] and the locations of annual deforestation derived from the Global Forest Change (GFC) website[49].

Combining information on forest cover, plantations, concession boundaries, and RSPO member plantations (certified and non-certified), we estimated the distributions of natural forest and three plantation ownership types (Figure 1): (1) RSPO-certified industrial plantations (CERT); (2) non-certified plantations within concession boundaries (which mainly includes the non-certified RSPO-member plantations and non-RSPO industrial-scale plantations) (CONC); (3) non-certified plantations outside concessions (largely includes independent smallholders (<25 ha) and small proportion of medium to large plantations (≥25 ha) with unknown concession permit) (NCONC) (Supplementary Figure 1). Areas outside natural forest and oil palm plantations mainly comprise agricultural lands, mixed plantations (e.g. rubber, coffee), shrubs, settlements, and infrastructure (Figure 1). Our impact evaluation focussed specifically on oil palm plantations within concession boundaries (CONC) and RSPO-certified plantations (CERT), and excluded those outside known concession permits (NCONC). Detailed methodologies for generating these spatial data are provided in Supplementary Methods 3.

Village primary livelihoods

Primary livelihood sectors across the villages in Sumatra, Kalimantan and Papua were derived from the *Potensi Desa* (PODES) census, collected from village heads by the Central Bureau of Statistics (BPS) of Indonesia roughly every three years between 2000 and 2018[37]. These data contain information on the socioeconomic and development status for each village administrative boundary. Three major livelihoods were identified via PODES: (1) subsistence production including small-scale farming for staple foods, fishing, and the collection of forest products, (2) agricultural plantations including both polyculture and monoculture plantations, and (3) other sectors including horticulture, aquaculture, livestock, agricultural services, and non-agricultural activities (Figure 3a). In the analysis, market-based livelihoods includes agricultural plantations (polyculture and monoculture) and other sectors[30,31].

Indicators of well-being

Village-level PODES data from 2000, 2003, 2005, 2008, 2011, 2014, and 2018 were used as proxy indicators for two aspects of village well-being, i.e. socioeconomic and socioecological (Santika *et al.* 2019a,b; Supplementary Table 1). The socioeconomic aspect includes living conditions, infrastructure, and income support, and the socioecological aspect includes security, social equity, and natural hazard prevention[50,51]. PODES provides the most comprehensive public information on land-use, population demographics, and village infrastructure available in Indonesia, and has been used extensively to inform government policy and development studies[52,53]. The choice of indicators and directionality of the effects on well-being listed in Supplementary Table 1 correspond to existing methodologies used to assess poverty and livelihoods[30,31], such as the Sustainable Livelihood Approach (SLA[34]), the Multidimensional Poverty Index (MPI[54]), and the Nested Spheres of Poverty (NESP[55]). Our categorization of indicators closely follows that advocated by the SLA[34,35], in which the socioeconomic grouping encapsulates the human (basic), physical, and financial dimensions of well-being, and the socioecological encapsulates social and natural dimensions (Supplementary Methods 2).

Analysis of land-use and livelihood change at village level

To capture the patterns of transition in primary land-use towards RSPO-certified plantations at village level, we classified each village into one of four categories based on the dominant land cover: (1) natural forest; (2) agricultural lands, mixed plantations and shrubs; (3) non-certified industrial oil palm plantations; and (4) RSPO-certified industrial oil palm plantations. Following a classification tree (Supplementary Figure 3), we first sorted villages based on the percentage of natural forest cover (primary and secondary forest): (1)

384 villages with ≥50% of the land area allocated to natural forest (hereafter termed as `villages with primarily
385 natural forest´); and (2) the remaining villages (>50% of the land areas allocated to agriculture, plantations,
386 shrubs and other land-uses). We then divided the second category based on the extent of industrial-scale
387 plantations: (1) villages with ≥10% of the land area allocated to planted industrial oil palm concession
388 (hereafter termed as `oil palm plantation villages´); and (2) those otherwise (hereafter termed as `villages with
389 primarily agricultural lands, mixed plantations, and shrubs´). Finally, we divided the `oil palm villages´ based
390 on the extent of certified plantations: (1) villages with ≥10% of the land area allocated to planted certified oil
391 palm concession (hereafter termed as `RSPO-certified plantation villages´); and (2) those otherwise
392 (hereafter termed as `Non-certified plantation villages´). We used the 10% threshold for defining the oil palm
393 plantation villages based on the median proportion of village land area allocated to industrial oil palm
394 plantations across Sumatra, Kalimantan and Papua (Supplementary Figure 4c, left plot). We also used the
395 10% threshold for defining RSPO-certified plantation villages for the same reason across Sumatra and
396 Kalimantan, noting there were insufficient certified plantations in Papua to evaluate impact there
397 (Supplementary Figure 4d).

398 We tracked the change in village primary land-use that leads to predominantly industrial-scale oil
399 palm plantations and RSPO certification between 2000 and 2018 across villages in Sumatra, Kalimantan and
400 Papua (see Supplementary Table 3 for the number of villages for assessed). To obtain an approximation of
401 the latent structure of land-use change, we used the observed village primary land-use in 2000, 2005, 2011,
402 and 2018 (Supplementary Figure 3).

403 To determine the livelihood dynamics associated with land-use change, we quantified the likelihood
404 of a village falling within the three livelihood classes (i.e. subsistence livelihoods; agricultural plantations; and
405 other sectors) for each primary land-use category (i.e. natural forest; agricultural lands, mixed plantations and
406 shrubs; non-certified industrial oil palm plantations; and RSPO-certified industrial oil palm plantations) in
407 2000, 2005, 2011 and 2018 (Figure 3a). To provide a nuanced understanding of the scale of plantations
408 (either small to medium landholders, or large-scale industrial plantations) associated with each livelihood
409 class, we calculated the average proportion of village plantations located within the boundaries of oil palm
410 concession. Larger proportions indicate a higher likelihood of the primary livelihood sector and economy in a
411 village being driven by large-scale monoculture oil palm plantations compared to small and medium-scale
412 plantations (Figure 3a). To assess the change in community composition and migration in the village, we also
413 quantified the likelihood of each village falling within three broad ethnic identities or classes (i.e. all people
414 identify as belonging to ethnic groups native to the island in question; majority belong to ethnic groups native

to the island; or majority belong to ethnic groups from outside the island) for each village primary land-use category over the same period (Figure 3b).

Analysis of impact evaluation

Spatial and temporal unit of analysis

We conducted two separate impact evaluation analyses on poverty: (A) the impact of industrial oil palm plantations, and (B) impact of RSPO certification. For both analyses, we used the village administrative boundary as the spatial unit of analysis, which was defined in the BPS census in 2014[56]. The impact of oil palm on the change in village well-being (analysis A) was determined 5-11 years after plantation development to allow for time delays in the accrual of well-being benefits, e.g. profits from harvesting[57] and infrastructure development[58], as well as manifestation of social and environmental impacts, e.g. conflicts[7-9], influx of workers[5], and pollution[12]. The impact of certification on the change in village well-being (analysis B) was also determined 5-11 years after certification. To do so, we compared the change in indicators between paired PODES censuses, i.e. 2000 and 2005 (5 years), 2000 and 2008 (8 years), 2000 and 2011 (11 years). The oil palm impact analysis covered 11 paired census data, and the analysis of certification impact covered three (Supplementary Table 4).

Units for treatment and counterfactual (control)

When evaluating the impact of industrial oil palm plantation development (analysis A), the units receiving treatment were villages with ≥10% of their land area allocated to industrial oil palm plantation over the full study periods, but not within the previous five years. We used the 10% threshold based on the approximate median proportion of village land area allocated to industrial oil palm plantations across Sumatra, Kalimantan and Papua (Supplementary Figure 4c, left plot). As the unit for counterfactuals or controls, we used villages where none of the land areas were allocated to industrial oil palm plantations over the range of the analysis period, nor in the five years prior to that (see conceptual diagram outlining the definitions in Supplementary Figure 5).

For the certification impact analysis (analysis B), the units receiving treatment were oil palm villages (i.e. villages with ≥10% of the land areas allocated to industrial oil palm plantations) where ≥10% of the land area were assigned to certified plantations over the full analysis periods, but no certified plantations were

detected within the previous three years. Again the 10% threshold for certification was based on the approximate median proportion of village land area allocated to certified plantations across Sumatra and Kalimantan (excluding Papua as few plantations were certified) (Supplementary Figure 4d). For the counterfactual, we used oil palm villages with the same proportion of their areas allocated to industrial oil palm plantations as that in the treated villages and where none of the plantations were certified over the analysis period, nor in the previous three years (Supplementary Figure 6).

Analytical framework

For each of two impact evaluations (oil palm and certification, separately) we followed four steps. First, for each island and time period (or paired PODES censuses) we generated the propensity score or likelihood for the spatial assignment of industrial oil palm plantations or certification based on a given set of biophysical and socioeconomic variables. Second, we applied a binary matching method for each island and time period to select control villages with similar baseline characteristics as those in the treated villages through nearest neighbour matching or search of propensity score and exact matching of key categorical variables. Third, we applied difference-in-difference regression to the matched dataset. Fourth, we conducted diagnostic tests and sensitivity analyses to verify the robustness of our estimates against modelling specification and approach. Detailed steps for conducting each impact evaluation are provided in Supplementary Methods 4.

Step 1: Generating propensity scores

We generated the propensity scores for each island (i.e. Sumatra, Kalimantan and Papua for analysis A; Sumatra and Kalimantan for analysis B) and time period by employing a non-parametric generalized boosted regression model (GBM) for binary outcomes implemented in the R-package gbm[59]. The GBM model allows flexibility in fitting non-linear response curves for predicting treatment assignment and can incorporate a large number of covariates without negatively affecting model prediction. We controlled for potentially confounding variables in each impact assessment in terms of both selections of villages for treatment and the outcome being measured (Supplementary Table 2). To achieve this, we included variables representing: (a) socio-political factors, (b) accessibility, (c) agricultural productivity, and (d) baseline village socioeconomic conditions. This selection is based on previous analyses of oil palm expansion without certification in Kalimantan[30,31].

Step 2: Applying the matching method

For analysis A, we employed a binary matching method[60] to select a set of control villages in which oil palm plantations had not been developed and that exhibited the same baseline characteristics as villages where plantations had been established. For analysis B, we applied the matching to select a set of control oil palm villages without certification and which exhibited the same baseline characteristics as oil palm villages where certification had been granted. Both analyses A and B were performed based on nearest-neighbour matching of propensity scores using all variables described in Supplementary Table 2 and exact matching of the categorical baseline variables (i.e. *KBPT, LZON, FORB, SOIL*, and *LVHD*). We applied a 0.25 calliper width of each propensity score standard deviation in the nearest neighbour approach, as this width was previously shown to be optimal[61]. Matching algorithms were implemented separately for each of the 18 indicators of well-being (Supplementary Table 1) in the R-package Matching[62].

For analysis A, the matching method was applied for each of the indicators (Supplementary Table 1), three islands (Sumatra, Kalimantan, and Papua), and 11 time periods (Supplementary Table 4), separately. We observed substantial improvement in the extent of overlapping areas of all continuous variables (*ELEV*, *SLOP*, *CITY*, *POPB*, *SDRY*, *SWET*, *TRNS,* and *VILA*) between villages with and without industrial oil palm plantation development in the matched dataset compared to the original (unmatched) dataset (Supplementary Figure 7 and Supplementary Table 5; aggregated across 18 indicators of well-being, three islands, and 11 time periods). For analysis B, the matching method was applied for each indicator (Supplementary Table 1), two islands (Sumatra and Kalimantan), and three time periods (Supplementary Table 4), separately. Again, we observed substantial improvement in the extent of overlapping areas of all continuous variables (*ELEV, SLOP, CITY, POPB, SDRY, SWET, TRNS, VILA*, and OPV) in the oil palm villages with and without certification after matching was performed (Supplementary Figure 8 and Supplementary Table 6; aggregated across 18 indicators of well-being, two islands, and three time periods).

Step 3: Difference-in-difference regression

For each indicator of well-being k, we first calculated the change or difference over 5–11 years (i.e. between two PODES censuses), and then multiplied the change by w_k (Supplementary Table 1). The value of w_k represents the directional effect of the change in indicator k that defines improvement in well-being, i.e. w_k=1 if positive change (or an increase) in indicator k represents improvement in well-being (e.g. proportion of household with electricity) and w_k= –1 if negative change (or a reduction) in indicator k represents improvement in well-being (e.g. prevalence of malnutrition, frequency of conflicts). We then divided the value by the maximum of the absolute change of well-being across all villages and time periods within each island. Thus, we obtained values that ranged roughly between -1 and 1, where -1 and 1 denote the largest reduction

and improvement in the well-being indicator across all study villages in each island, respectively, and 0 denotes no change in the well-being indicator after 5-11 years. We applied this transformation approach mainly to preserve information about the directionality of change in well-being (i.e. relative improvement or reduction) over time, and to allow comparable measures across different indicators.

The impact of industrial oil palm plantations (analysis A) on village-level well-being was estimated by comparing the change in well-being indicators in villages with oil palm plantation development with the change in control villages without plantations, i.e. the difference in the differences in well-being indicators between two PODES censuses between oil palm and non oil palm villages, for each island and village livelihood type. The impact of oil palm certification (analysis B) on village-level well-being was estimated by comparing the change in well-being indicators in oil palm villages with certified plantations with the change in control oil palm villages without certification, i.e. the difference in the differences in well-being indicators between two PODES censuses between certified and non certified oil palm villages, for each island and village livelihood type. The number of villages assessed for both analyses is shown in Supplementary Table 3. The overall effect (and confidence interval) of industrial oil palm plantations or RSPO certification on improving each aspect of well-being for each island and livelihood type was obtained by pooling estimates across all indicators belonging to the same group of well-being aspect (Supplementary Table 1).

Step 4: Diagnostic tests and sensitivity analyses

To assess the quality of our matched dataset we examined the change in the distributions of variables potentially affecting the assignments of industrial oil palm plantation villages (for analysis A) or certified plantation villages (for analysis B) before and after matching procedure. We achieved bias reduction of 92.9-98.6% for covariates matched in analysis A (Supplementary Table 5), and 81.7-98.3% for analysis B (Supplementary Table 6), indicating that samples were strongly matched in both assessments.

We conducted a series of sensitivity analyses to verify the robustness of our estimates against modelling specification and approach. This included: (1) generating propensity scores separately within island, time period, and livelihood type, in contrast to our main approach of generating the scores within island and time period; and (2) applying different categorization of well-being indicators by shifting indicators security and social equity from socioecological to socioeconomic aspects. The alternative method for generating the propensity scores yielded similar conclusions about the impact of oil palm development (analysis A) and certification (analysis B) on well-being as those generated by the main approach (Supplementary Figure 9). The alternative grouping of indicators under the socioeconomic and

socioecological aspects resulted in worsened performance of industrial oil palm development (analysis A) and certification (analysis B) on village well-being than those obtained from the main approach (Supplementary Figure 10). This is because the negative impact of oil palm development or certification on key indicators of social well-being (i.e. prevalence of conflicts and low wage agricultural labourers) tended to be less pronounced than the negative impact on natural hazard prevalence, but worse than the impact on living conditions, infrastructure provision, and income support (Extended Data Figures 6-7).

Data availability

Key datasets used to conduct our analysis are publicly available from the cited references (forest cover data available from https://glad.umd.edu/dataset/primary-forest-cover-loss-indonesia-2000-2012 and https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html and socioeconomic data from https://mikrodata.bps.go.id/mikrodata/index.php/catalog/PODES).

References

1. Meijaard, E., Garcia-Ulloa, J., Sheil, D., Carlson, K., Wich, S.A. *et al.* (2018) *Oil Palm and Biodiversity – A Situation Analysis.* IUCN Oil Palm Task Force, Gland, Switzerland.
2. Directorate General of Estate Crops Indonesia (2019) *Tree Crop Estate Statistics of Indonesia 2017-2019*. Jakarta.
3. Sayer, J., Ghazoul, J., Nelson, P. & Boedhihartono, A.K. (2012) Oil palm expansion transforms tropical landscapes and livelihoods. *Global Food Security* **1**, 114-119.
4. Susanti, A. & Maryudi, A. (2016) Development narratives, notions of forest crisis, and boom of oil palm plantations in Indonesia. *Forest Policy and Economics* **73**, 130-139.
5. Potter, L. (2012) New transmigration 'paradigm' in Indonesia: Examples from Kalimantan. *Asia Pacific Viewpoint* **53**, 272–287.
6. Pye, O. (2019) Commodifying sustainability: Development, nature and politics in the palm oil industry. *World Development* **121**, 218-228.
7. McCarthy, J.F. (2010) Processes of inclusion and adverse incorporation: oil palm and agrarian change in Sumatra, Indonesia. *The Journal of Peasant Studies* **37**, 821-850.
8. Colchester, M. (2011) *Palm Oil and Indigenous Peoples in South East Asia*. Forest Peoples Programme.
9. Li, T.M. (2017) Intergenerational displacement in Indonesia's oil palm plantation zone. *The Journal of Peasant Studies* **44**, 1158-1176.
10. Gaveau, D.L., Locatelli, B., Salim, M.A., Yaen, H., Pacheco, P. *et al.* (2019) Rise and fall of forest loss and industrial plantations in Borneo (2000–2017). *Conservation Letters* **12**, e12622.
11. White, B.N.F. (2012) Gendered experiences of dispossession: Oil palm expansion in a Dayak Hibun community in West Kalimantan. *The Journal of Peasant Studies* **39**, 995–1016.
12. Carlson, K.M., Curran, L.M., Ponette□González, A.G., Ratnasari, D., Lisnawati, N. *et al.* (2014) Influence of watershed□climate interactions on stream temperature, sediment yield, and metabolism along a land use intensity gradient in Indonesian Borneo. *Journal of Geophysical Research: Biogeosciences* **119**, 1110-1128.
13. Merten, J., Röll, A., Guillaume, T., Meijide, A., Tarigan, S. *et al*. (2016) Water scarcity and oil palm expansion: social views and environmental processes. *Ecology and Society* **21**, 5.

14. Luke, S.H., Barclay, H., Bidin, K., Chey, V.K., Ewers, R.M. *et al.* (2017) The effects of catchment and riparian forest quality on stream environmental conditions across a tropical rainforest and oil palm landscape in Malaysian Borneo. *Ecohydrology* **10**, e1827.
15. Wells, J.A., Wilson, K.A., Abram, N.K., Nunn, M., Gaveau, D.L.A. *et al.* (2016) Rising floodwaters: mapping impacts and perceptions of flooding in Borneo. *Environmental Research Letters* **11**, 064016.
16. Carlson, K.M., Curran, L.M., Asner, G.P., Pittman, A.M., Trigg, S.N. *et al.* (2013) Carbon emissions from forest conversion by Kalimantan oil palm plantations. *Nature Climate Change* **3**, 283.
17. Marlier, M.E., DeFries, R.S., Kim, P.S., Koplitz, S.N., Jacob, D.J. *et al.* (2015) Fire emissions and regional air quality impacts from fires in oil palm, timber, and logging concessions in Indonesia. *Environmental Research Letters* **10**, 085005.
18. Tan-Soo, J.S. & Pattanayak, S.K. (2019) Seeking natural capital projects: Forest fires, haze, and early-life exposure in Indonesia. *Proceedings of the National Academy of Sciences* **116**, 5239-5245.
19. Santika, T., Budiharta, S., Law, E.A., Dennis, R.A., Dohong, A. *et al.* (2020) Interannual climate variation, land type and village livelihood effects on fires in Kalimantan, Indonesia. *Global Environmental Change* **64**, 102129.
20. RSPO (2018) *RSPO Principles & Criteria Certification For the Production of Sustainable Palm Oil*. Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia.
21. RSPO (2019a) *Impact Report*. Available at: https://rspo.org/about/impacts. Accessed 4 October 2019.
22. RSPO (2019b) *RSPO Jurisdictional Approach*.
23. Ruysschaert, D. & Salles, D. (2014) Towards global voluntary standards: Questioning the effectiveness in attaining conservation goals: The case of the Roundtable on Sustainable Palm Oil (RSPO). *Ecological Economics* **107**, 438-446.
24. De Man, R. & German, L. (2017) Certifying the sustainability of biofuels: Promise and reality. *Energy Policy* **109**, 871-883.
25. Cattau, M.E., Marlier, M.E. & DeFries, R. (2016) Effectiveness of Roundtable on Sustainable Palm Oil (RSPO) for reducing fires on oil palm concessions in Indonesia from 2012 to 2015. *Environmental Research Letters* **11**, 105007.
26. Carlson, K.M., Heilmayr, R., Gibbs, H.K., Noojipady, P., Burns, D.N. et al. (2018) Effect of oil palm sustainability certification on deforestation and fire in Indonesia. *Proceedings of the National Academy of Sciences* **115**, 121-126.

27. Morgans, C.L., Meijaard, E., Santika, T., Law, E., Budiharta, S. *et al.* (2018) Evaluating the effectiveness of palm oil certification in delivering multiple sustainability objectives. *Environmental Research Letters* **13**, 064032.
28. Furumo, P.R., Rueda, X., Rodríguez, J.S. & Ramos, I.K.P. (2019) Field evidence for positive certification outcomes on oil palm smallholder management practices in Colombia. *Journal of Cleaner Production* **245***,* 118891.
29. Heilmayr, R., Carlson, K.M. & Benedict, J.J. (2020) Deforestation spillovers from oil palm sustainability certification. *Environmental Research Letters* **15**, 075002.
30. Santika, T., Wilson, K.A., Budiharta, S., Law, E.A., Poh, T.M. *et al.* (2019a) Does oil palm agriculture help alleviate poverty? A multidimensional counterfactual assessment of oil palm development in Indonesia. *World Development* **120**, 105-117.
31. Santika, T., Wilson, K.A., Meijaard, E., Budiharta, S., Law, E.A. *et al.* (2019b) Changing landscapes, livelihoods and village welfare in the context of oil palm development. *Land Use Policy* **87**, 104073.
32. Jerneck, A. & Olsson, L. (2013) More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. *Journal of Rural Studies* **32**, 114-125.
33. Chan, K.M., Goldstein, J., Satterfield, T., Hannahs, N., Kikiloi, K*. et al.* (2011) Cultural services and non-use values. In: *Natural Capital: Theory and Practice of Mapping Ecosystem Services*, pp. 206-228.
34. Scoones, I. (1998) *Sustainable Rural Livelihoods: A Framework for Analysis.* IDS Working Paper 72. Sussex: Brighton Institute of Development Studies, University of Sussex.
35. Liu, Y. & Xu, Y. (2016) A geographic identification of multidimensional poverty in rural China under the framework of sustainable livelihoods analysis. *Applied Geography* **73**, 62-76.
36. Sen, A. (2006) Conceptualizing and measuring poverty. In: *Poverty and Inequality*, pp. 30-46.
37. Bureau of Statistic (BPS) Indonesia (2019) *Village Potential Statistics (PODES) 2000, 2003, 2005, 2008, 2014, and 2018*. Jakarta, Indonesia.
38. Setiawan, E.N., Maryudi, A., Purwanto, R.H. & Lele, G. (2016) Opposing interests in the legalization of non-procedural forest conversion to oil palm in Central Kalimantan, Indonesia. *Land Use Policy* **58**, 472-481.
39. Gupta, J., Pouw, N.R. & Ros-Tonen, M.A. (2015) Towards an elaborated theory of inclusive development. *The European Journal of Development Research* **27**, 541-559.
40. Dauvergne, P. & Neville, K.J. (2010) Forests, food, and fuel in the tropics: the uneven social and ecological consequences of the emerging political economy of biofuels. *The Journal of Peasant Studies* **37**, 631-660.

633 41. Budidarsono, S., Susanti, A. & Zoomers, A. (2013) Oil palm plantations in Indonesia: The implications
634 for migration, settlement/resettlement and local economic development. In: *Biofuels – Economy,*
635 *Environment and Sustainability*. Intech, Rijeka (Croatia), pp. 173-193.
636 42. Schoneveld, G.C., van der Haar, S., Ekowati, D., Andrianto, A., Komarudin, H. *et al.* (2019)
637 Certification, good agricultural practice and smallholder heterogeneity: Differentiated pathways for
638 resolving compliance gaps in the Indonesian oil palm sector. *Global Environmental Change* **57**,
639 101933.
640 43. Gaveau, D.L.A., Pirard, R., Salim, M.A., Tonoto, P., Yaen, H. *et al.* (2017) Overlapping land claims limit
641 the use of satellites to monitor no-deforestation commitments and no-burning compliance.
642 *Conservation Letters* **10**, 257-264.
643 44. Jelsma, I., Schoneveld, G.C., Zoomers, A. & Van Westen, A.C.M. (2017) Unpacking Indonesia's
644 independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and
645 social performance challenges. *Land Use Policy* **69**, 281-297.
646 45. Waldman, K.B. & Kerr, J.M. (2014) Limitations of certification and supply chain standards for
647 environmental protection in commodity crop production. *Annual Review of Resource Economics* **6**, 429-
648 449.
649 46. Klasen, S., Meyer, K.M., Dislich, C., Euler, M., Faust, H. *et al*. (2016) Economic and ecological trade-
650 offs of agricultural specialization at different spatial scales. *Ecological Economics* **122**, 111-120.
651 47. Dislich, C., Keyel, A.C., Salecker, J., Kisel, Y., Meyer, K.M. *et al*. (2017) A review of the ecosystem
652 functions in oil palm plantations, using forests as a reference system. *Biological Reviews* 92, 1539-
653 1569.

654 **IN METHODS ONLY**

655 48. Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F. & Hansen, M.C. (2014) Primary forest cover
656 loss in Indonesia over 2000–2012. *Nature Climate Change* **4**, 730.
657 49. Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S. *et al.* (2013) High-resolution
658 global maps of 21st-century forest cover change. *Science* **342**, 850-853.
659 50. Bergamini, N., Blasiak, R., Eyzaguirre, P., Ichikawa, K., Mijatovic, D. *et al*. (2013) *Indicators of*
660 *Resilience in Socio-ecological Production Landscapes (SEPLs)*. United Nations University Institute of
661 Advanced Studies (UNU-IAS).
662 51. Dale, V.H., Efroymson, R.A., Kline, K.L., Langholtz, M.H., Leiby, P.N. *et al.* (2013) Indicators for
663 assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures.
664 *Ecological Indicators* **26**, 87-102.

52. Miteva, D.A., Loucks, C.J. & Pattanayak, S.K. (2015) Social and environmental impacts of forest management certification in Indonesia. *PLoS One* **10**, e0129675.
53. Lee, J.S.H., Miteva, D.A., Carlson, K.M., Heilmayr, R. & Saif, O. (2020) Does the oil palm certification create trade-offs between environment and development in Indonesia? SocArXiv. DOI: 10.31219/osf.io/zrwpd
54. Alkire, S., Chatterjee, M., Conconi, A., Seth, S., & Vaz, A. (2014) *Global Multidimensional Poverty Index 2014*. OPHI Briefing 21. Oxford: University of Oxford.
55. Gönner, C., Haug, M., Cahyat, A., Wollenberg, E., DeJong, W. *et al.* (2007) *Capturing Nested Spheres of Poverty: A Model for Multidimensional Poverty Analysis and Monitoring.* CIFOR Occasional Paper No. 46. Bogor, Indonesia: Center for International Forestry Research.
56. Bureau of Statistic (BPS) Indonesia (2014) *Digital Map of Local Statistical Area 2014*. Jakarta, Indonesia.
57. Lee, J.S.H., Ghazoul, J., Obidzinski, K., & Koh, L.P. (2014) Oil palm smallholder yields and incomes constrained by harvesting practices and type of smallholder management in Indonesia. *Agronomy for Sustainable Development* **34**, 501–513.
58. Gatto, M., Wollni, M., Asnawi, R. & Qaim, M. (2017) Oil palm boom, contract farming, and rural economic development: Village-level evidence from Indonesia. *World Development* **95**, 127-140.
59. Ridgeway, G. (2017) *gbm: Generalized Boosted Regression Models.* R Package Version 2.1.1. 2015.
60. Dehejia, R.H. & Wahba, S. (2002) Propensity score-matching methods for nonexperimental causal studies. *Review of Economics and Statistics* **84**, 151-161.
61. Austin, P.C. (2011) Optimal caliper widths for propensity - score matching when estimating differences in means and differences in proportions in observational studies. *Pharmaceutical Statistics* **10**, 150-161.
62. Sekhon, J.S. (2015) *Multivariate and Propensity Score Matching With Balance Optimization*. R Package Version 4.9-2.

Figure captions

Figure 1. Change in distribution of forest and oil palm plantations in Sumatra, Kalimantan and Papua. The change in the distribution of forest and oil palm plantations every 9 years between 2000 and 2018 across three major Indonesian islands: (a) Sumatra, (b) Kalimantan, and (c) Papua. Oil palm plantations are grouped into three categories: (1) RSPO-certified plantations, i.e. certified large-scale industrial plantations (CERT), (2) non-certified plantations within oil palm concessions, i.e. non RSPO-certified large-scale industrial plantations (CONC), and (3) non-certified plantations outside known oil palm concessions, i.e. mainly independent small-scale landholders and medium to large-scale plantations with unknown concession status (NCONC) (see Methods). Detailed maps for portions of each island are provided in Extended Data Figures 2-4.

Figure 2. Village land-use (and associated livelihood) pathways to oil palm certification. (a) The change in village primary land-use, from (1) high natural forest cover to (2) agricultural lands, mixed plantations and shrubs, followed by (3) industrial oil palm plantations (non-certified), then finally becoming (4) RSPO-certified industrial plantations. (b) The change in village primary livelihoods and community composition most likely associated with the change in village primary land-use, from (1) subsistence-based livelihoods in complex agroforestry systems (weak market exposure) dominated by indigenous communities, to (2) polyculture plantation (smallholding) livelihoods (moderate market exposure) dominated by indigenous communities and a higher proportion of migrants, then finally becoming (3) monoculture oil palm plantation livelihoods (stronger market-driven) with a high proportion of migrants.

Figure 3. Village primary livelihoods and ethnic features or identities by village primary land-use. (a) Proportion of villages with primary livelihoods subsistence-based, agricultural plantations, and other sectors, and proportion of village land area allocated to natural forest, polyculture plantations, monoculture plantations, and other land-uses for each livelihood class, by village primary land-use (natural forest; agricultural lands, plantations, and shrubs; non-certified industrial oil palm plantations; and RSPO-certified industrial oil palm plantations), averaged across 2000, 2005, 2011 and 2018 data. (b) Proportion of villages within each land-use type that are composed of people who all, or mostly identify themselves belonging to ethnic groups native, versus non-native, to the island.

Figure 4. Village land-use (and the associated livelihood) change matrix to oil palm plantation and certification. (a) Change in village primary land-use (and the associated primary livelihoods) between 2000

and 2018, from natural forest; agricultural lands, mixed plantations and shrubs; and non-certified industrial oil palm plantations in 2000; to non-certified industrial oil palm plantations and RSPO-certified plantations in 2018, in Sumatra, Kalimantan, and Papua. (b) Schematic diagram of transition of village primary land-use (and the associated livelihoods) between 2000 and 2018 from left to right, representing different development stages of the industrial oil palm plantations for Papua, Kalimantan, and Sumatra, i.e. early, intermediate, and advanced stage, respectively. The boxes in Figure 4b represent the development stage of the island, not necessarily the parts where oil palm expanded. We used 6 villages in each box to best resemble the matrix described in Figure 4a.

Figure 5. Impact of oil palm plantation development and certification on well-being in oil palm-growing villages. (a) Impact of oil palm plantations on village-level well-being, evaluated by comparing the change in well-being indicators in villages with oil palm after 5-11 years of plantation development against the change in well-being in villages without oil palm across Sumatra, Kalimantan and Papua. (b) Impact of RSPO certification on village-level well-being, evaluated by comparing the change in well-being indicators in villages with certified plantation after 5-11 years of certification against the change in well-being in villages with non-certified oil palm plantations across Sumatra and Kalimantan. In both analyses comparisons are made between village types with similar baseline characteristics appropriate to the datasets analysed. N represents the number of villages assessed in each panel. Error bars represent 95% confidence intervals of combination of all indicators in the groups.

Figure 6. Trends in the change of village well-being through the oil palm and certification processes. Trends in the change of socioeconomic and socioecological well-being indices within 5-11 years (median 8 years) before and after oil palm development, and within 5-11 years (median 8 years) after oil palm certification. Villages are partitioned by their baseline primary livelihoods (a) subsistence-based livelihoods typical of the majority of plantations in Kalimantan, or (b) market-based livelihoods typical of most villages with oil palm in Sumatra and Papua. N represents the number of villages assessed in each panel. Error bars represent 95% confidence intervals. It is worth noting that the baseline characteristics of samples for generating the left (Non-OP –> OP) and right (OP –> Cert) panels are different, thus the counterfactual comparisons should only be made within panels. The estimates in T-8 time period are the same between the treated and control villages because the samples were matched.

Oil palm plantations

- RSPO-certified plantations (CERT)
- Non-certified plantations within oil palm concessions (CONC)
- Non-certified plantations outside oil palm concessions (NCONC)

Non oil palm plantations

- Natural forest (primary and secondary forest)
- Non-forest land (agricultural lands, mixed plantations, shrubs, settlements, and infrastructure)

a SUMATRA

2000

Area ('000 km^2)
CERT = 0.0
CONC = 18.4
NCONC = 33.5
TOTAL = 51.9

2009

Area ('000 km^2)
CERT = 1.1
CONC = 20.4
NCONC = 35.3
TOTAL = 56.8

2018

Area ('000 km^2)
CERT = 7.3
CONC = 21.2
NCONC = 52.8
TOTAL = 81.3

b KALIMANTAN

2000

Area ('000 km^2)
CERT = 0.0
CONC = 8.1
NCONC = 5.3
TOTAL = 13.4

2009

Area ('000 km^2)
CERT = 0.2
CONC = 17.9
NCONC = 10.1
TOTAL = 28.2

2018

Area ('000 km^2)
CERT = 7.0
CONC = 31.7
NCONC = 14.5
TOTAL = 53.2

C PAPUA

2000

Area ('000 km^2)
CERT = 0.0
CONC = 0.4
NCONC = 0.2
TOTAL = 0.6

2009

Area ('000 km^2)
CERT = 0.0
CONC = 0.6
NCONC = 0.2
TOTAL = 0.8

2018

Area ('000 km^2)
CERT = 0.0
CONC = 1.5
NCONC = 0.6
TOTAL = 2.1

TRANSITION TO CERTIFIED OIL PALM PLANTATIONS AT VILLAGE LEVEL

a

Transition in primary land use

NATURAL FOREST

AGRICULTURAL LANDS, MIXED PLANTATIONS & SHRUBS

NON-CERTIFIED INDUSTRIAL OIL PALM PLANTATIONS

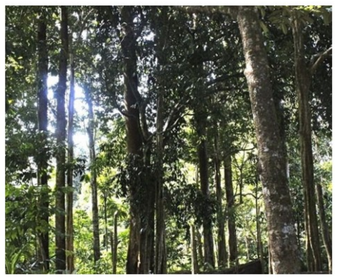
RSPO-CERTIFIED INDUSTRIAL OIL PALM PLANTATIONS

1 2 3 4

b

Transition in primary livelihoods and community composition

SUBSISTENCE-BASED (FARMING, FISHING & FOREST PRODUCT GATHERING)



POLYCULTURE PLANTATIONS (SMALLHOLDINGS)

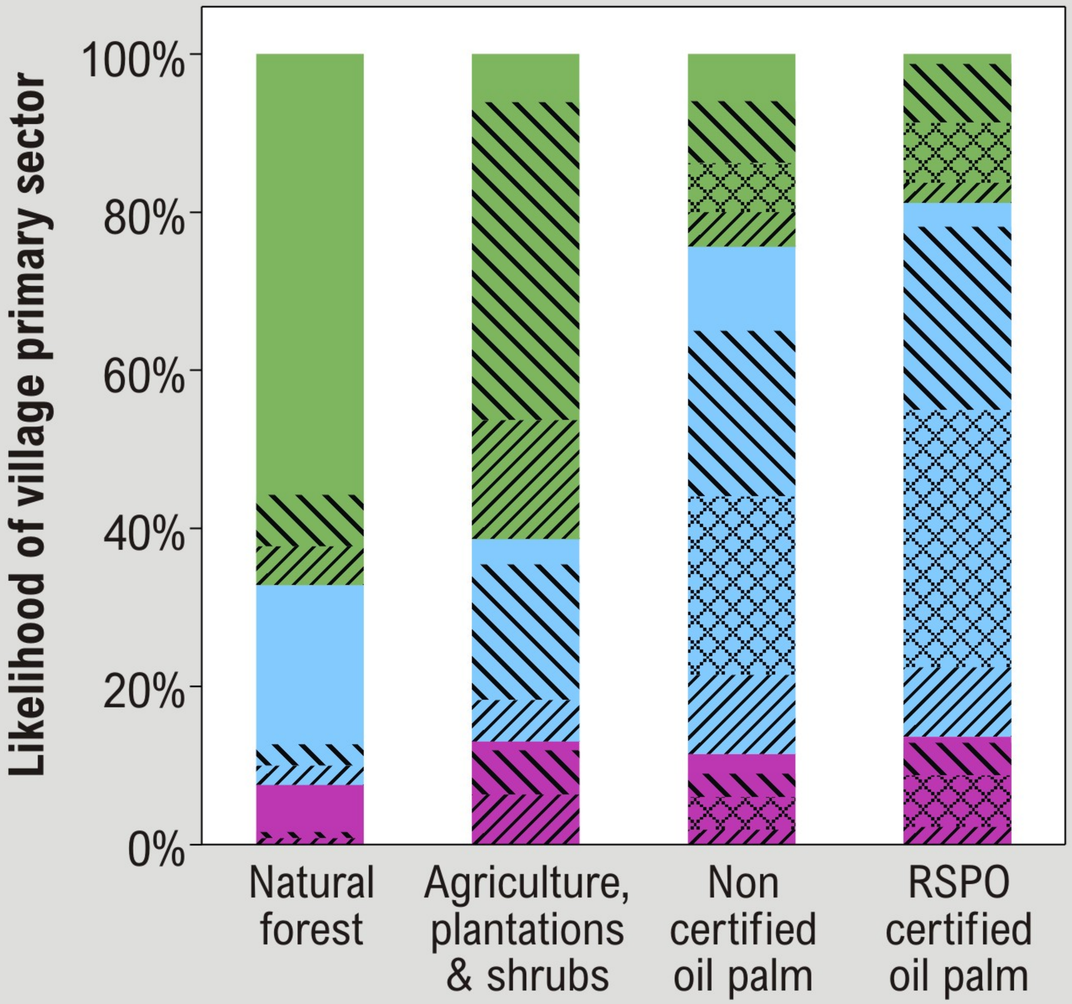
MONOCULTURE OIL PALM PLANTATIONS

MONOCULTURE OIL PALM PLANTATIONS

Weak ← **Market economy** → *Strong*

Indigenous ← **Dominant community** → *Migrants*

a

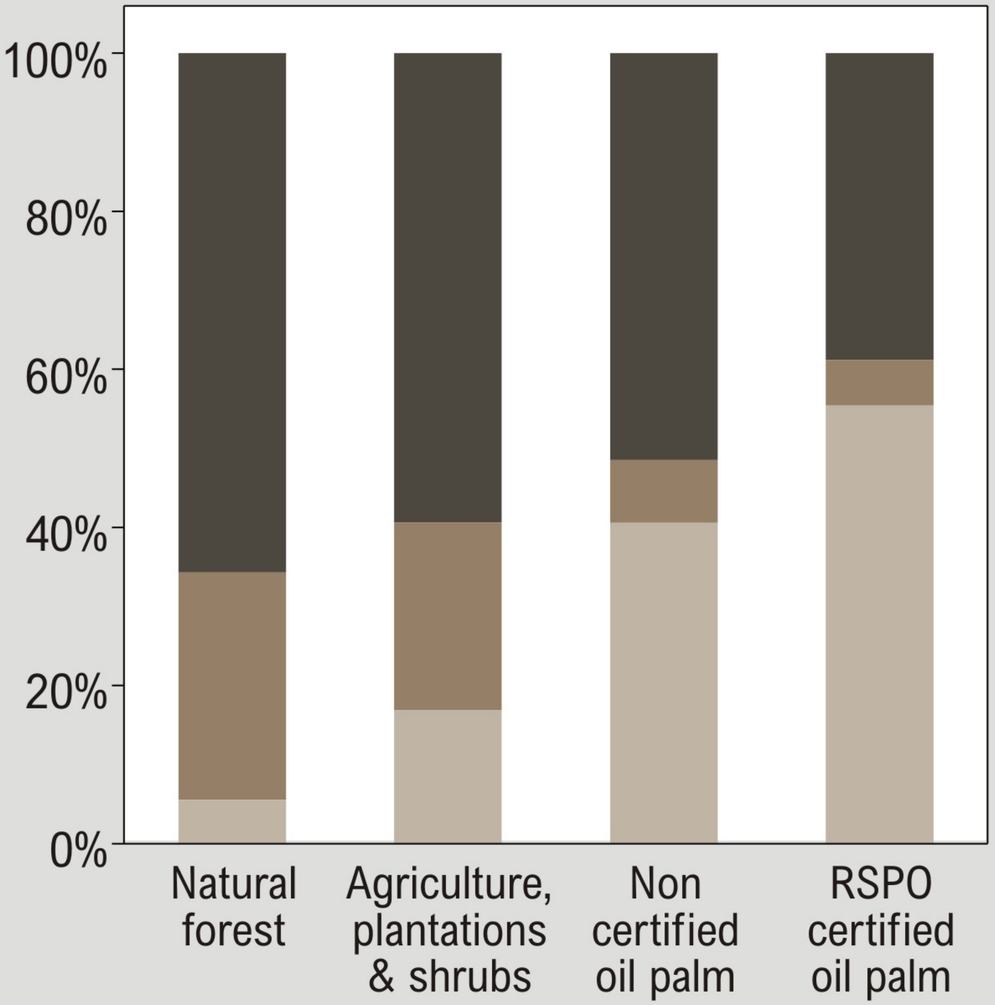


Proportion of villages with primary livelihood sector
- Subsistence-based
- Agricultural plantations
- Other sectors

Proportion of village land area allocated to
- Natural forest
- Polyculture plantations
- Monoculture plantations
- Other land uses

for each livelihood sector

b



Proportion of villages composed of people who are
- All native to the island
- Mostly native to the island
- Mostly recent migrants

a

SUMATRA

2000 \ 2018		
	6%	0%
	6%	0%
	70%	18%

KALIMANTAN

2000 \ 2018		
	41%	11%
	6%	2%
	29%	11%

PAPUA

2000 \ 2018		
	12%	0%
	30%	0%
	58%	0%

	Village primary land use	Village primary livelihoods
	Natural forest (primary & secondary forest)	Subsistence-based (farming, fishing, forest product gathering)
	Agricultural lands, mixed plantations & shrubs	Polyculture plantations (smallholdings)
	Non-certified industrial oil palm plantations	Monoculture oil palm plantations
	RSPO-certified industrial oil palm plantations	Monoculture oil palm plantations

b

(Intermediate development stage)

2000 **KALIMANTAN** 2018

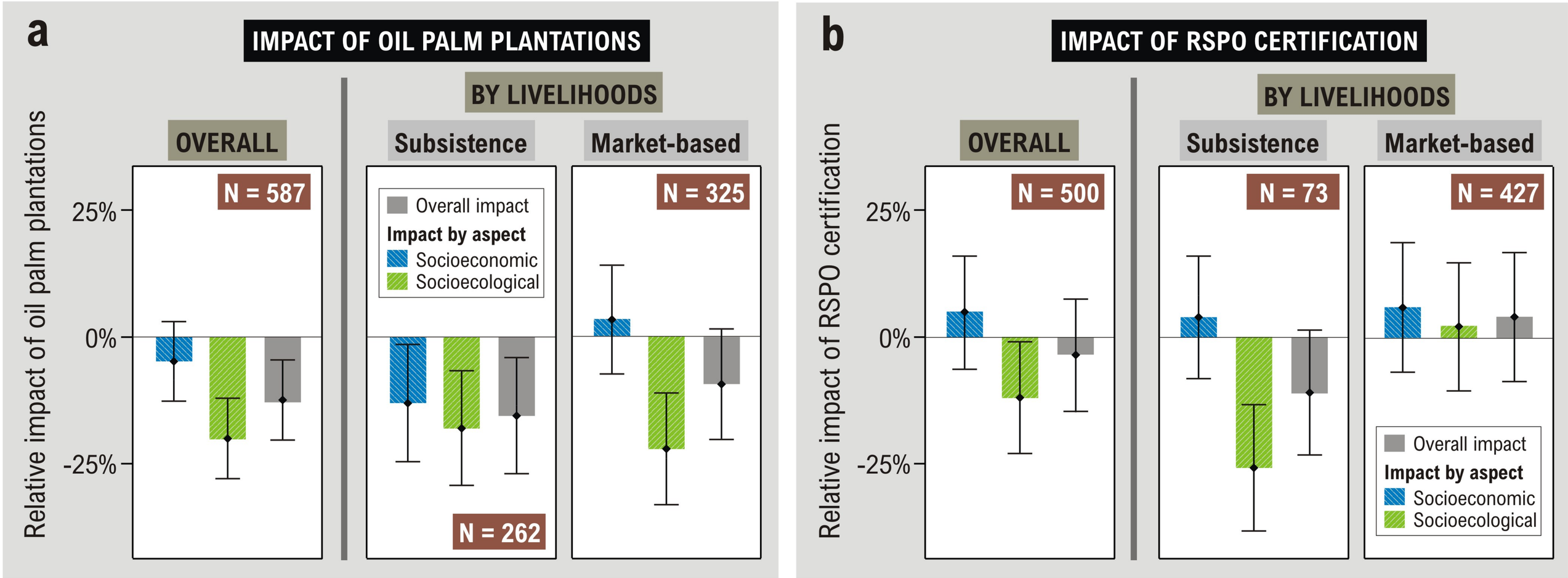
Village A · Village B · Village C · Village D · Village E · Village F

2000 **PAPUA** 2018

(Early development stage)

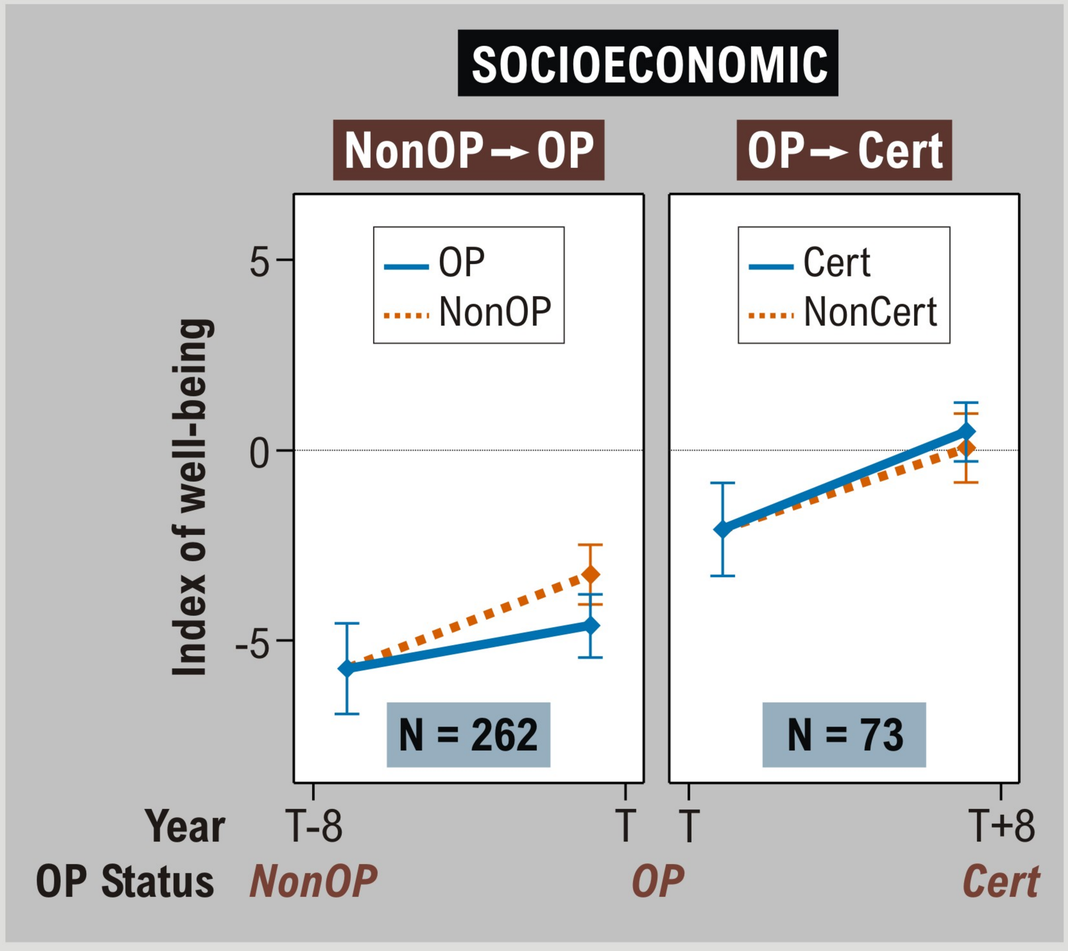
2000 **SUMATRA** 2018

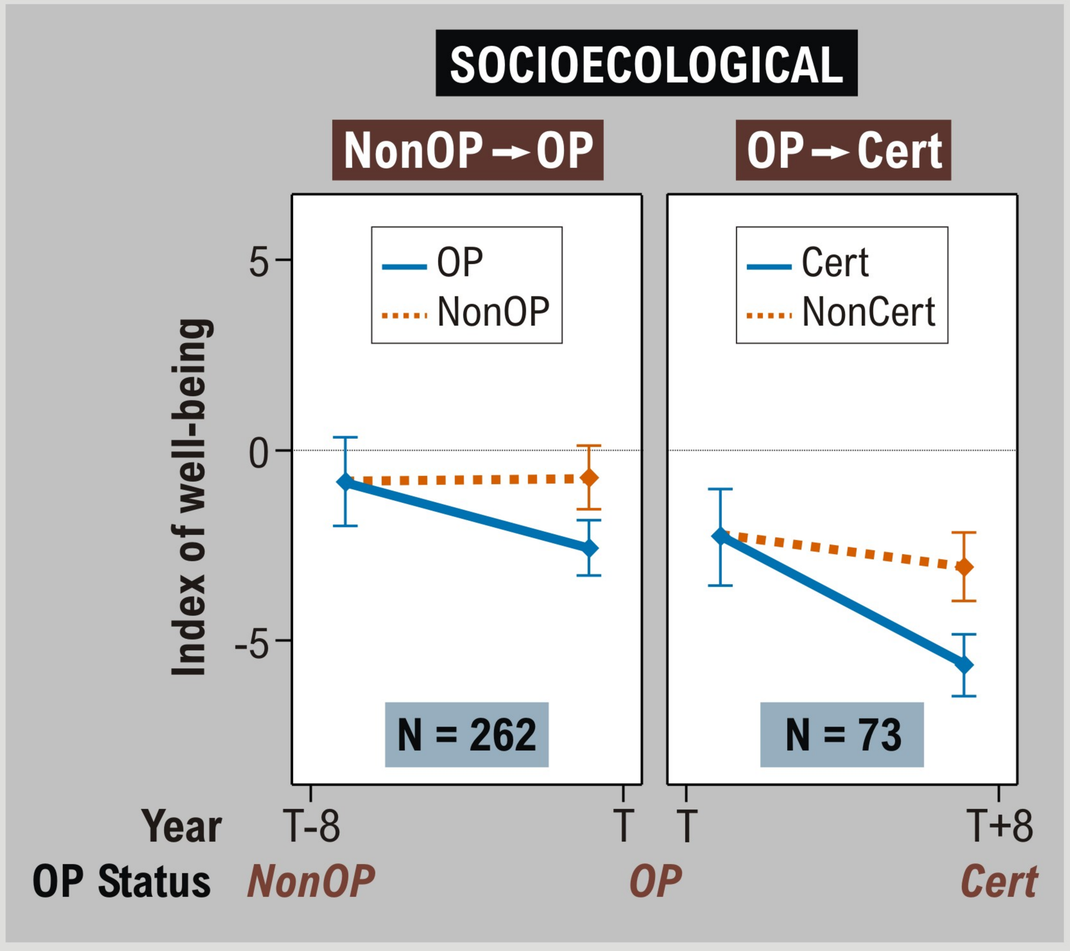
(Advanced development stage)


a
IMPACT OF OIL PALM PLANTATIONS
BY LIVELIHOODS
OVERALL
Subsistence
Market-based
Relative impact of oil palm plantations
25%
0%
-25%
N = 587
N = 262
N = 325
Overall impact
Impact by aspect
Socioeconomic
Socioecological
b
IMPACT OF RSPO CERTIFICATION
BY LIVELIHOODS
OVERALL
Subsistence
Market-based
Relative impact of RSPO certification
25%
0%
-25%
N = 500
N = 73
N = 427
Overall impact
Impact by aspect
Socioeconomic
Socioecological

a

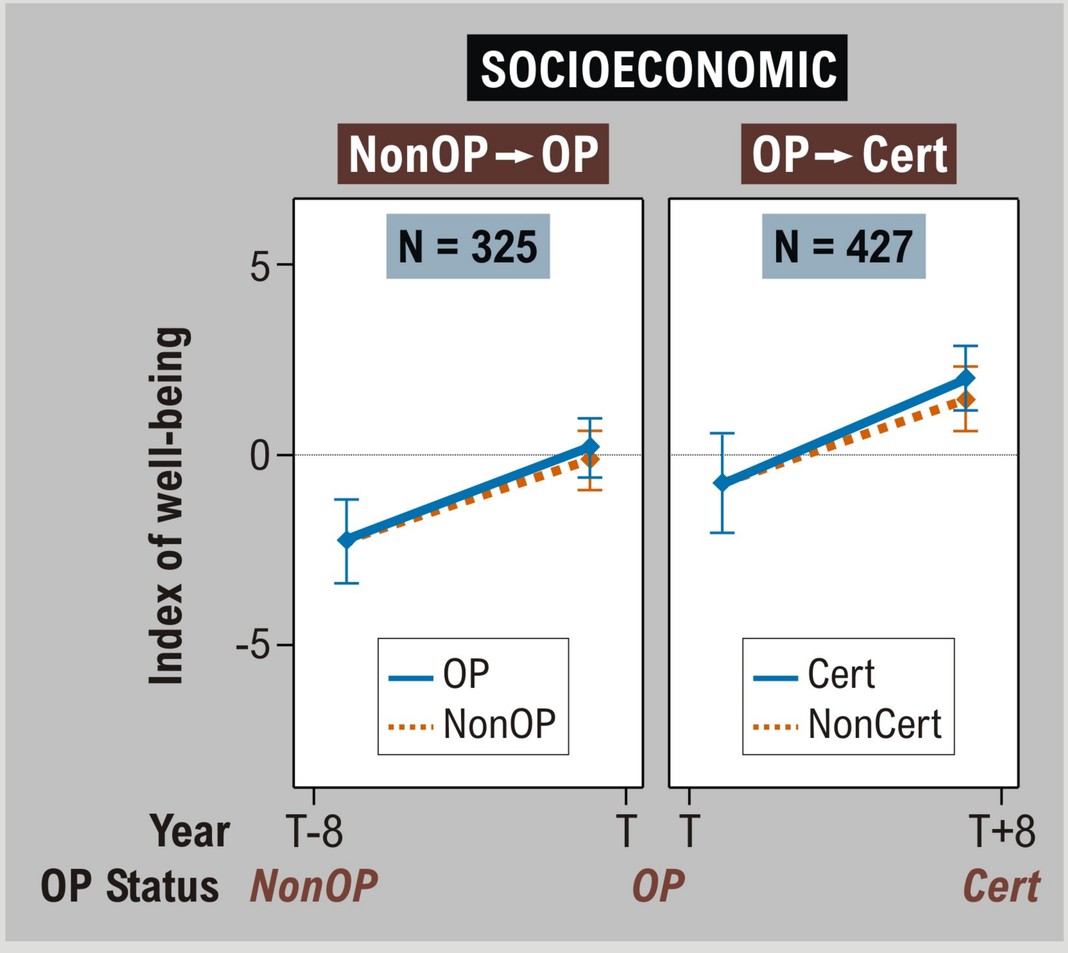
SUBSISTENCE LIVELIHOODS PRIOR TO OIL PALM OR CERTIFICATION

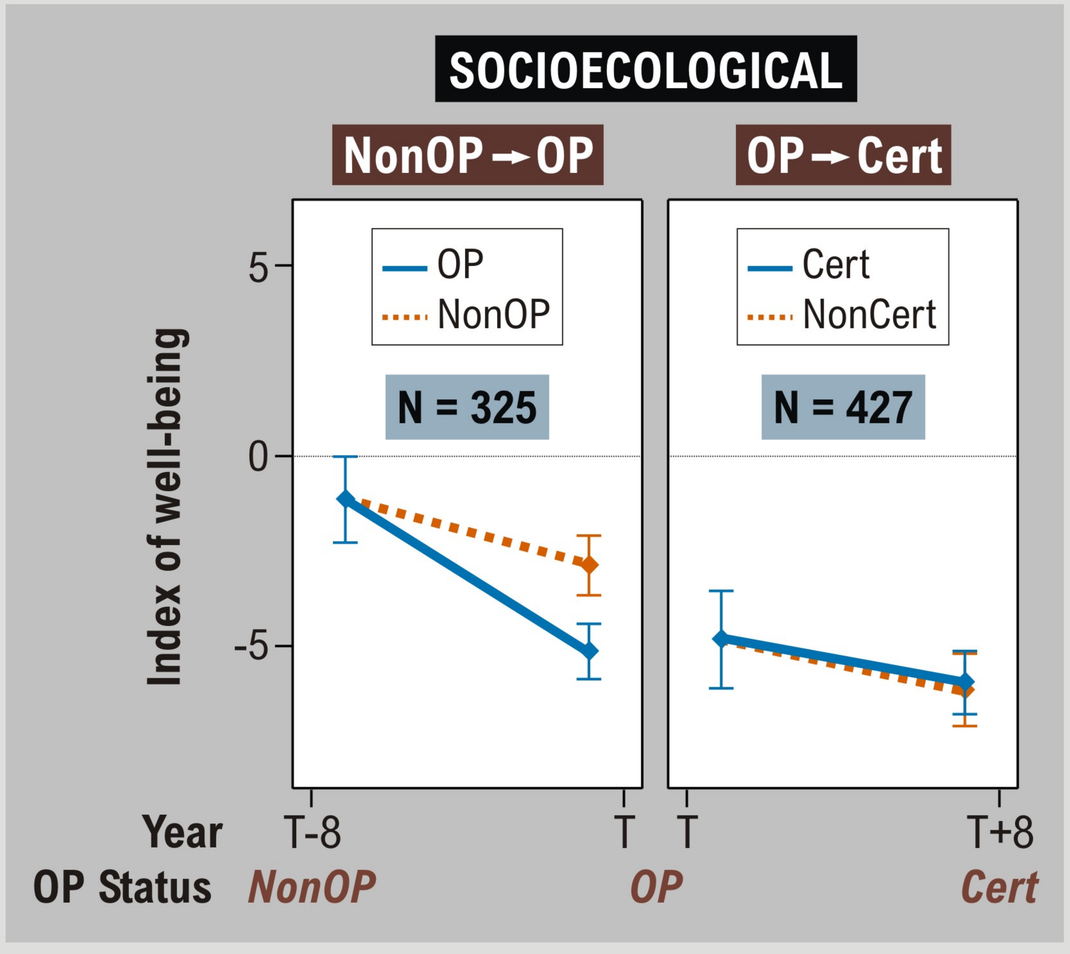




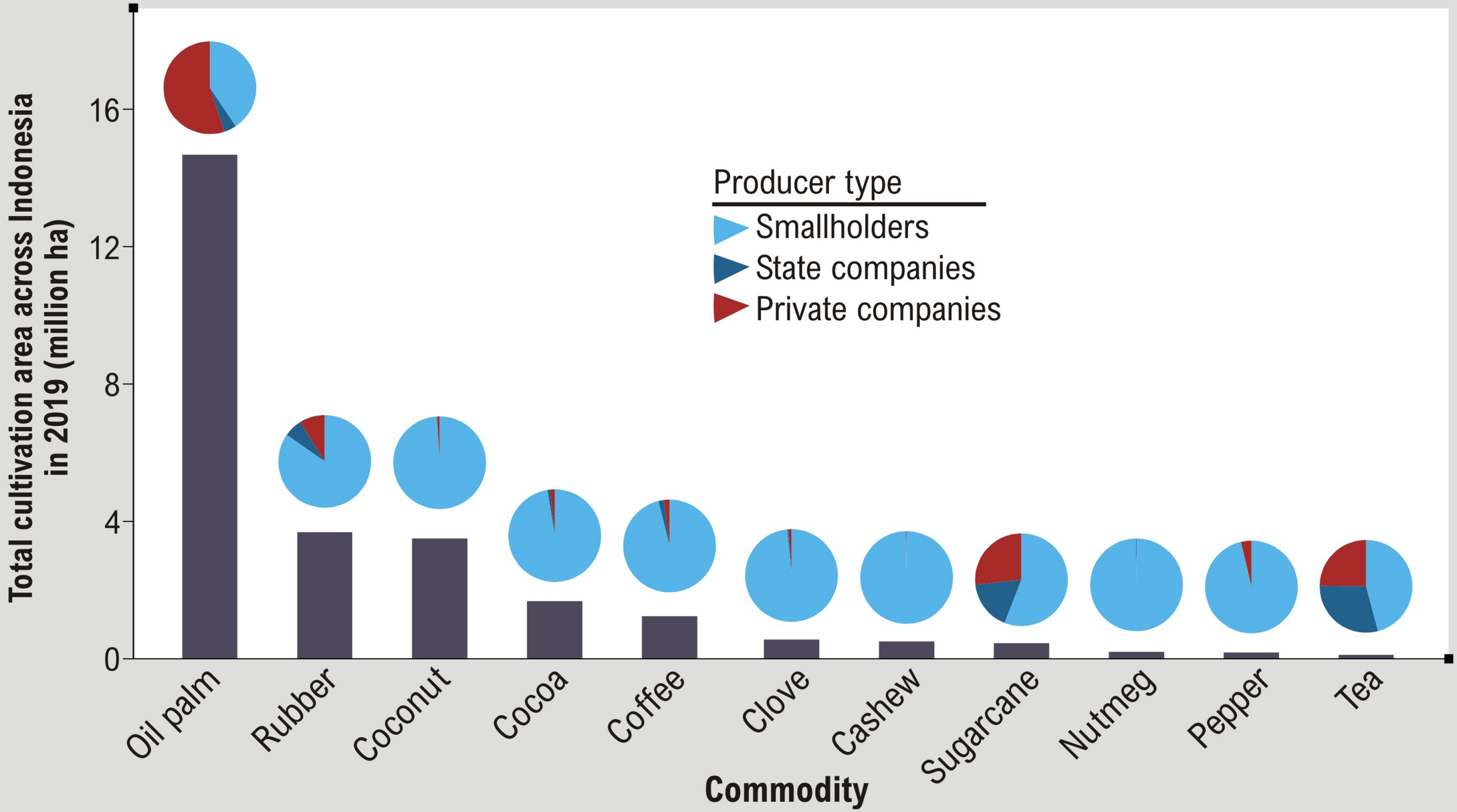
b

MARKET-BASED LIVELIHOODS PRIOR TO OIL PALM OR CERTIFICATION

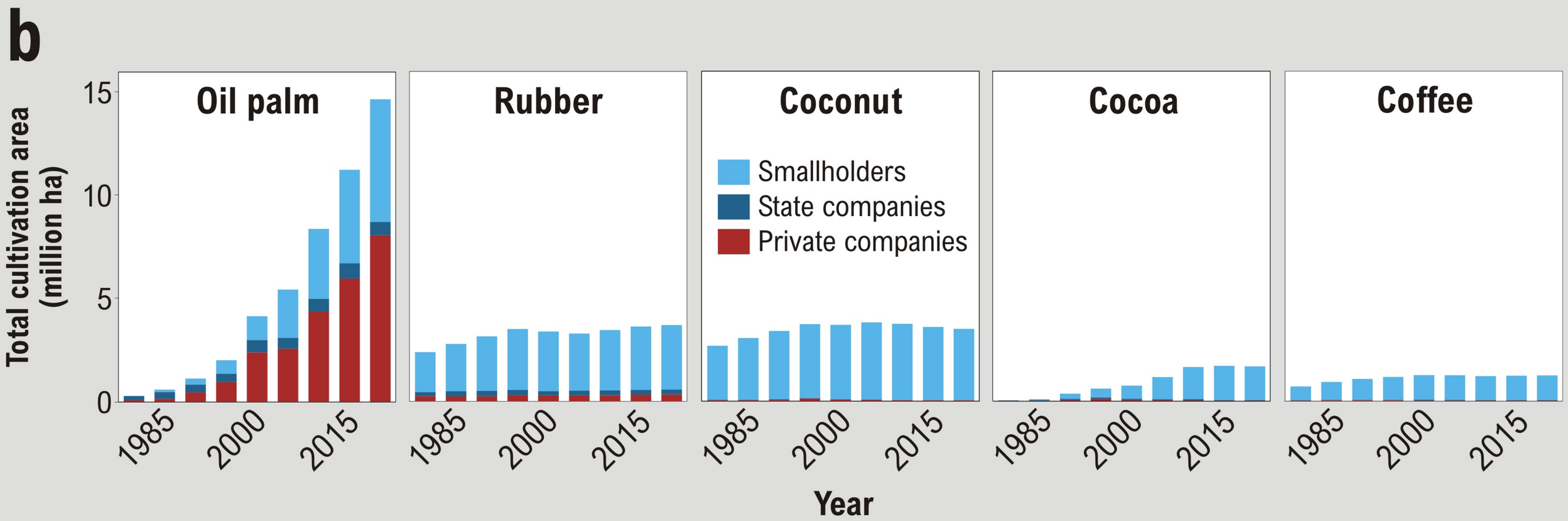


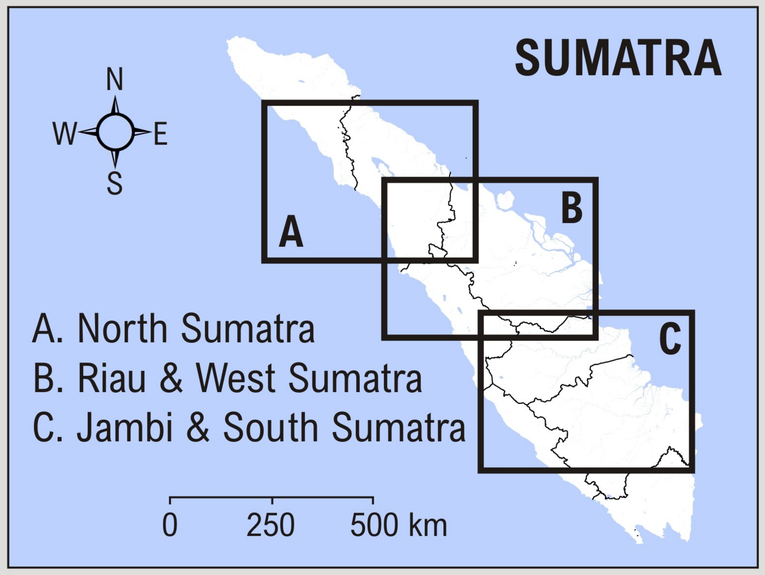


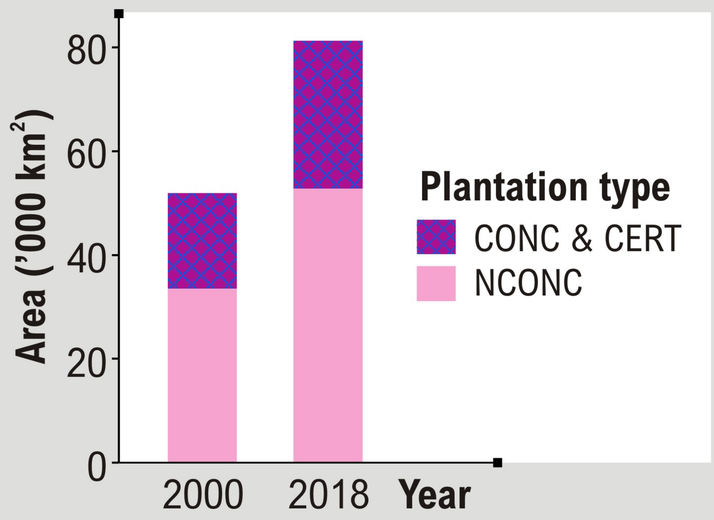
a


Total cultivation area across Indonesia in 2019 (million ha)
0
4
8
12
16
Producer type
Smallholders
State companies
Private companies
Oil palm
Rubber
Coconut
Cocoa
Coffee
Clove
Cashew
Sugarcane
Nutmeg
Pepper
Tea
Commodity

b

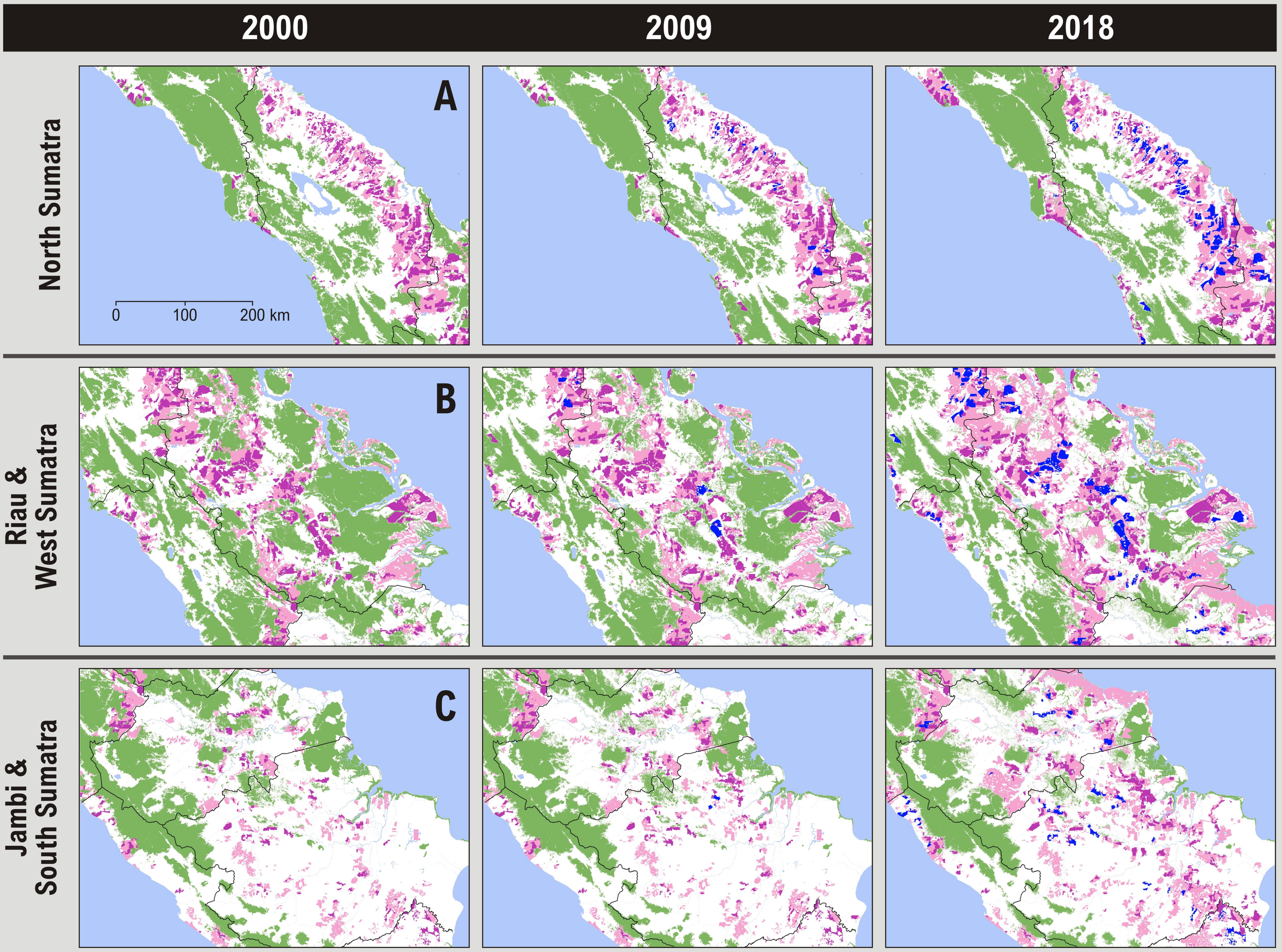

Total cultivation area (million ha)
0
5
10
15
Oil palm
Rubber
Coconut
Cocoa
Coffee
Smallholders
State companies
Private companies
1985
2000
2015
Year

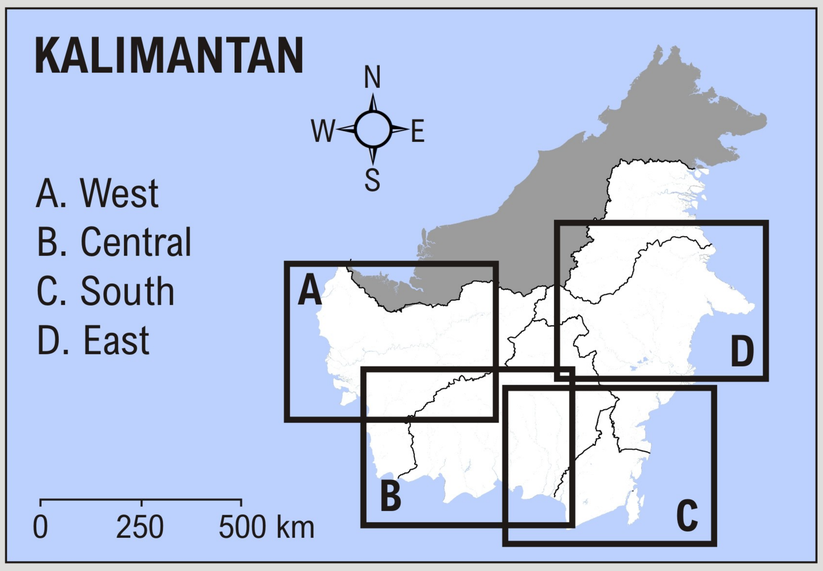


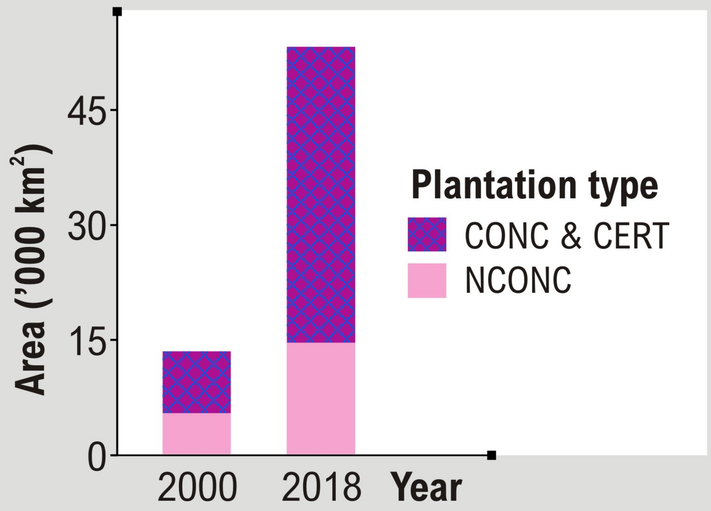


SUMATRA

Oil palm plantation type	Ratio of 2018 to 2000
CONC & CERT	1.55
NCONC	1.58
TOTAL	1.57

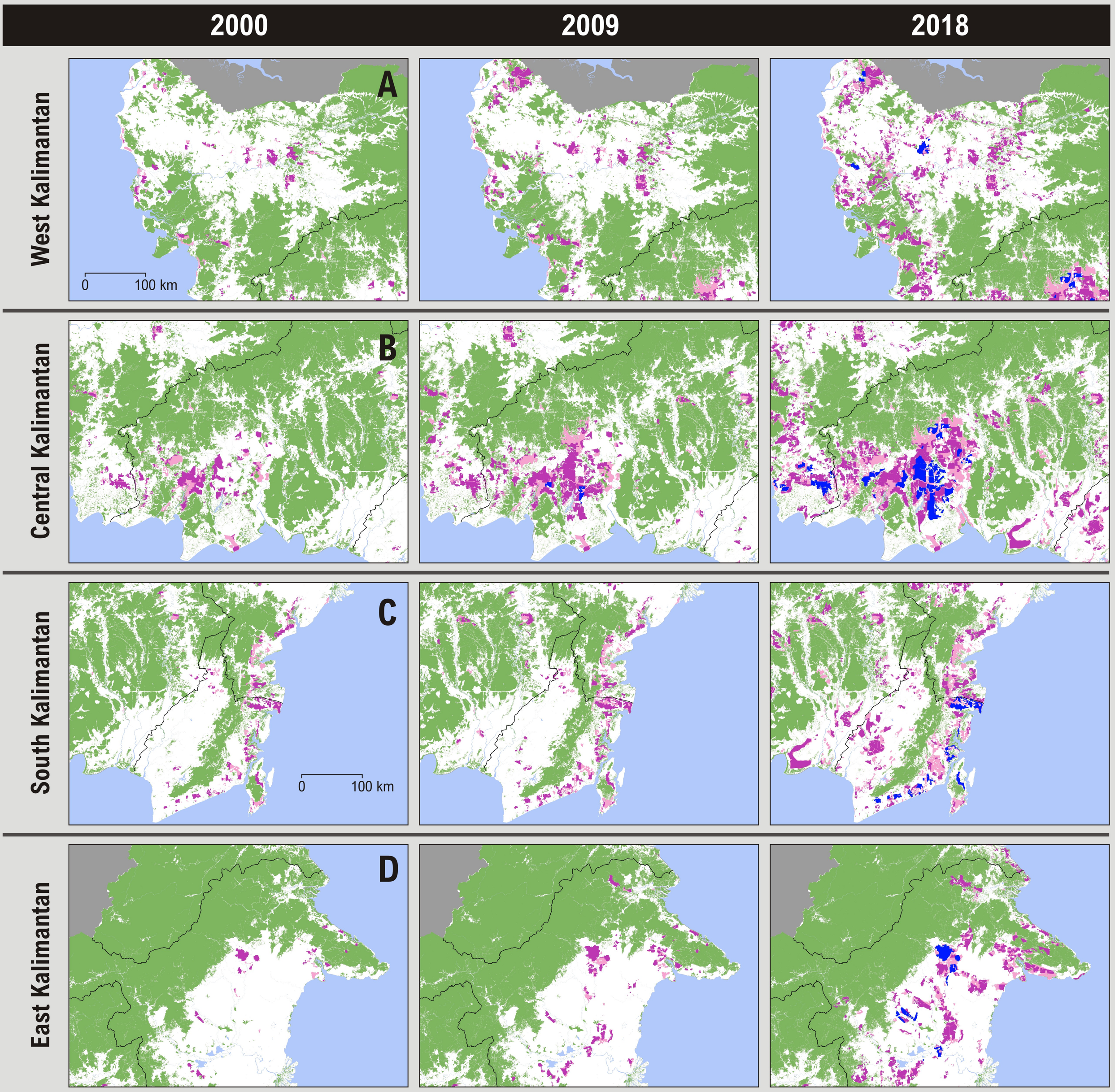


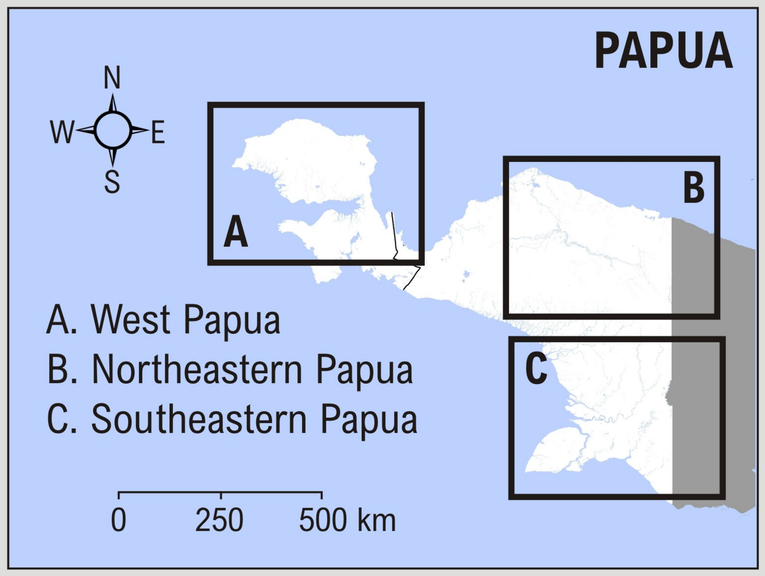


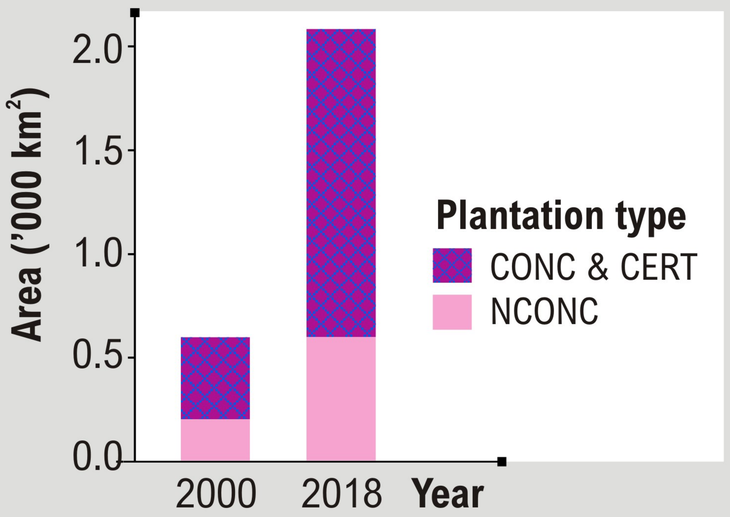


KALIMANTAN

Oil palm plantation type	Ratio of 2018 to 2000
CONC & CERT	4.78
NCONC	2.74
TOTAL	3.97

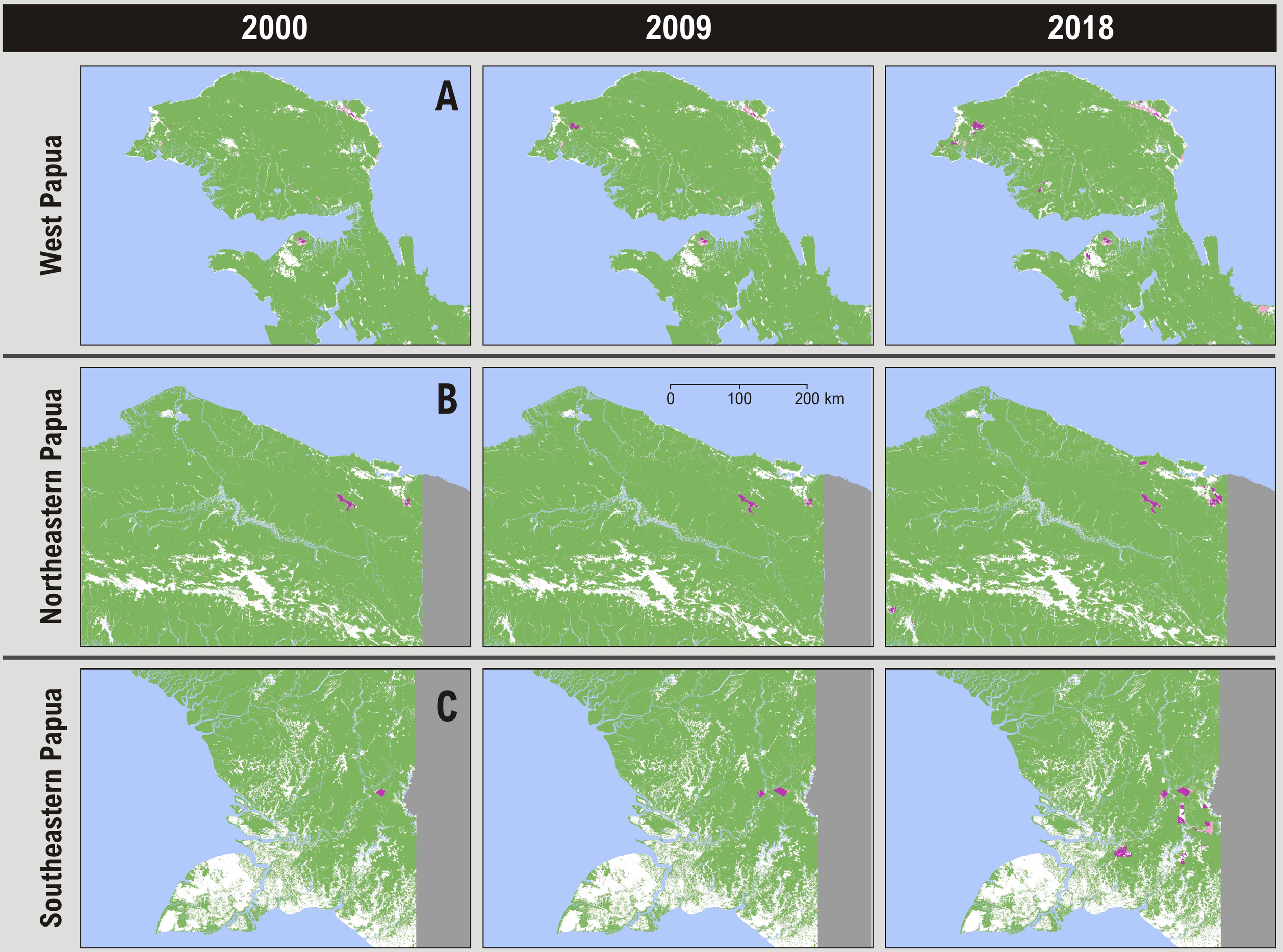






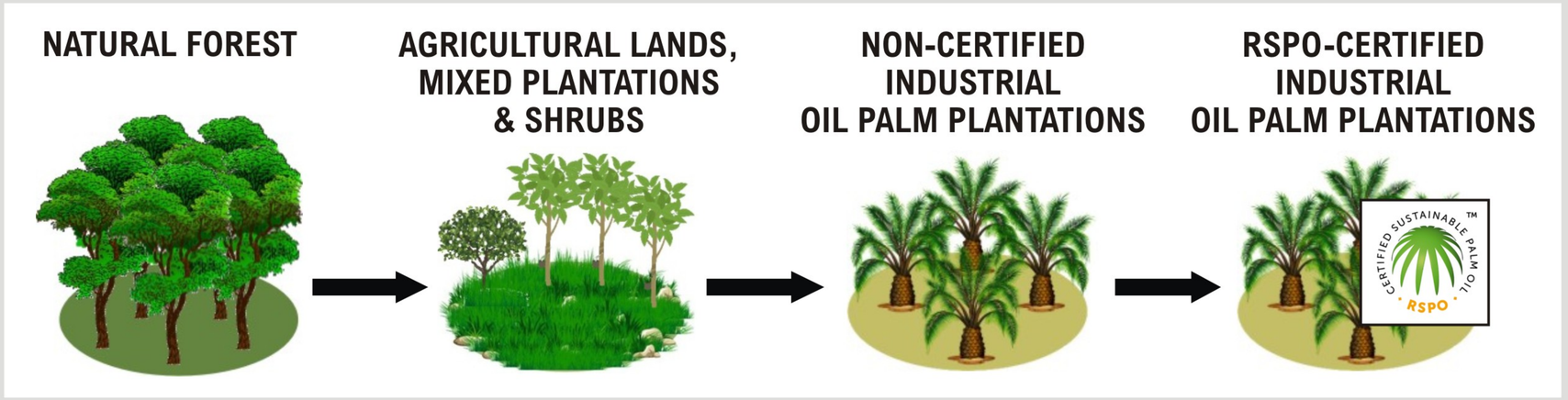
PAPUA

Oil palm plantation type	Ratio of 2018 to 2000
CONC & CERT	3.75
NCONC	3.00
TOTAL	3.50



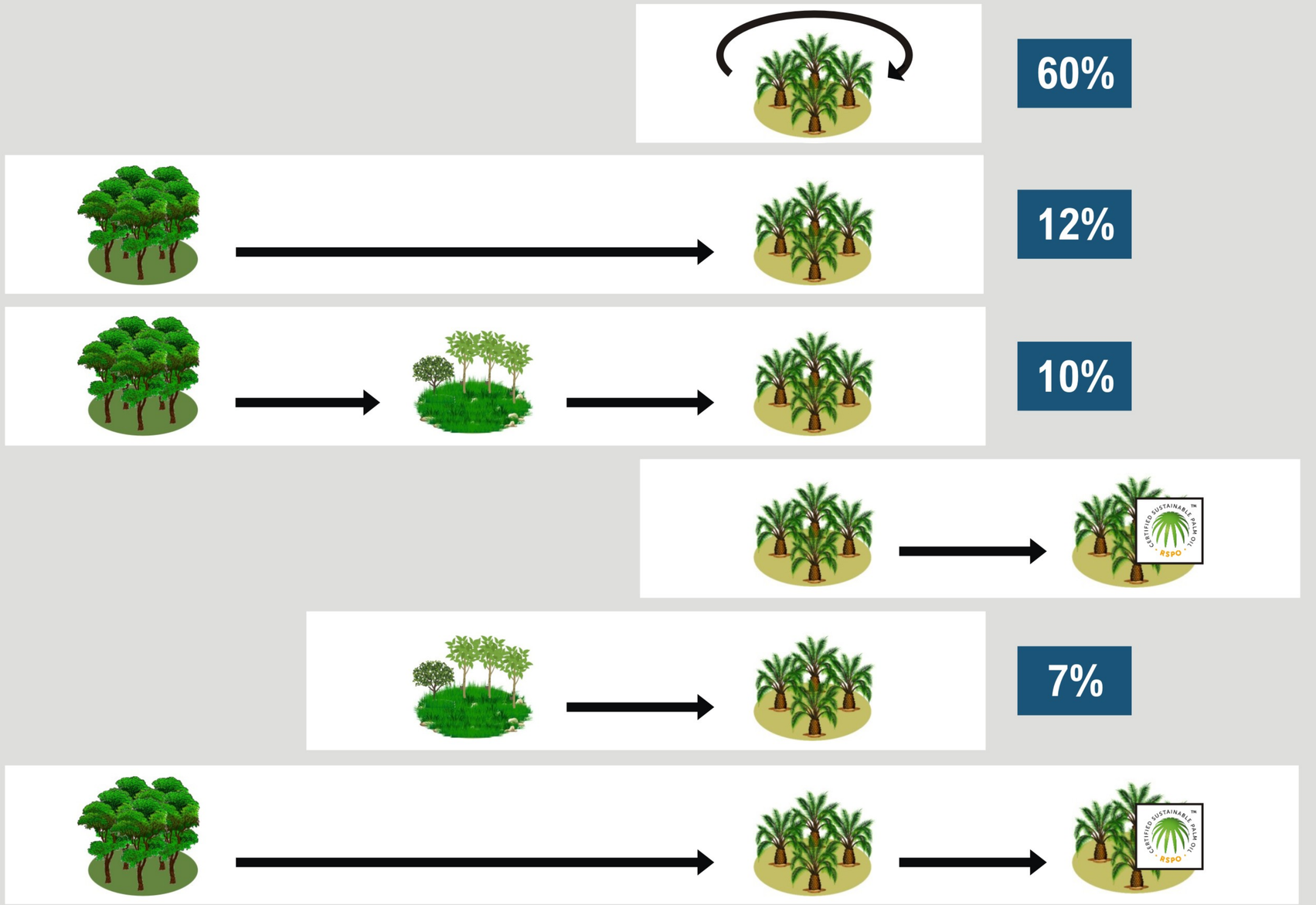
a

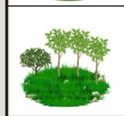
Latent transition of village primary land use (and the associated livelihoods) to industrial oil palm plantations and RSPO certification

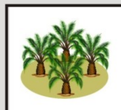


b

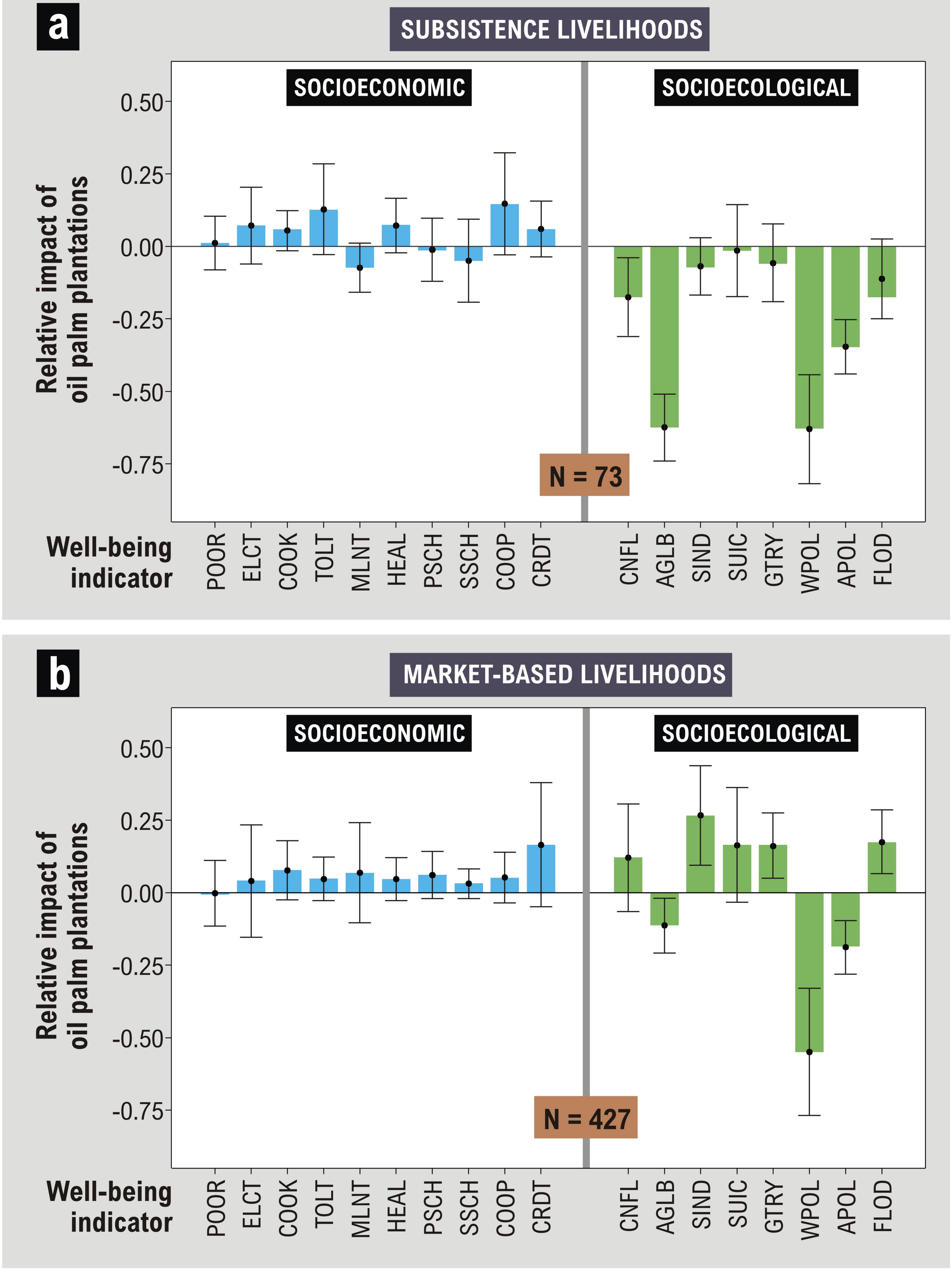
Observed transition of village primary land use (and the associated livelihoods) to industrial oil palm plantations and RSPO certification, aggregated across Sumatra, Kalimantan and Papua



	Village primary land use	Village primary livelihoods
	Natural forest (primary & secondary forest)	Subsistence-based (farming, fishing, forest product gathering)
	Agricultural lands, mixed plantations & shrubs	Polyculture plantations (smallholdings)

	Village primary land use	Village primary livelihoods
	Non-certified industrial oil palm plantations	Monoculture oil palm plantations
	RSPO-certified industrial oil palm plantations	Monoculture oil palm plantations

OP → CERT


a
SUBSISTENCE LIVELIHOODS
SOCIOECONOMIC
SOCIOECOLOGICAL
Relative impact of oil palm plantations
0.50
0.25
0.00
-0.25
-0.50
-0.75
N = 73
Well-being indicator
POOR
ELCT
COOK
TOLT
MLNT
HEAL
PSCH
SSCH
COOP
CRDT
CNFL
AGLB
SIND
SUIC
GTRY
WPOL
APOL
FLOD
b
MARKET-BASED LIVELIHOODS
SOCIOECONOMIC
SOCIOECOLOGICAL
Relative impact of oil palm plantations
0.50
0.25
0.00
-0.25
-0.50
-0.75
N = 427
Well-being indicator
POOR
ELCT
COOK
TOLT
MLNT
HEAL
PSCH
SSCH
COOP
CRDT
CNFL
AGLB
SIND
SUIC
GTRY
WPOL
APOL
FLOD

Non-OP → OP

a

SUBSISTENCE LIVELIHOODS

SOCIOECONOMIC

SOCIOECOLOGICAL

Relative impact of oil palm plantations

0.50
0.25
0.00
-0.25
-0.50
-0.75

N = 262

Well-being indicator

POOR ELCT COOK TOLT MLNT HEAL PSCH SSCH COOP CRDT | CNFL AGLB SIND SUIC GTRY WPOL APOL FLOD

b

MARKET-BASED LIVELIHOODS

SOCIOECONOMIC

SOCIOECOLOGICAL

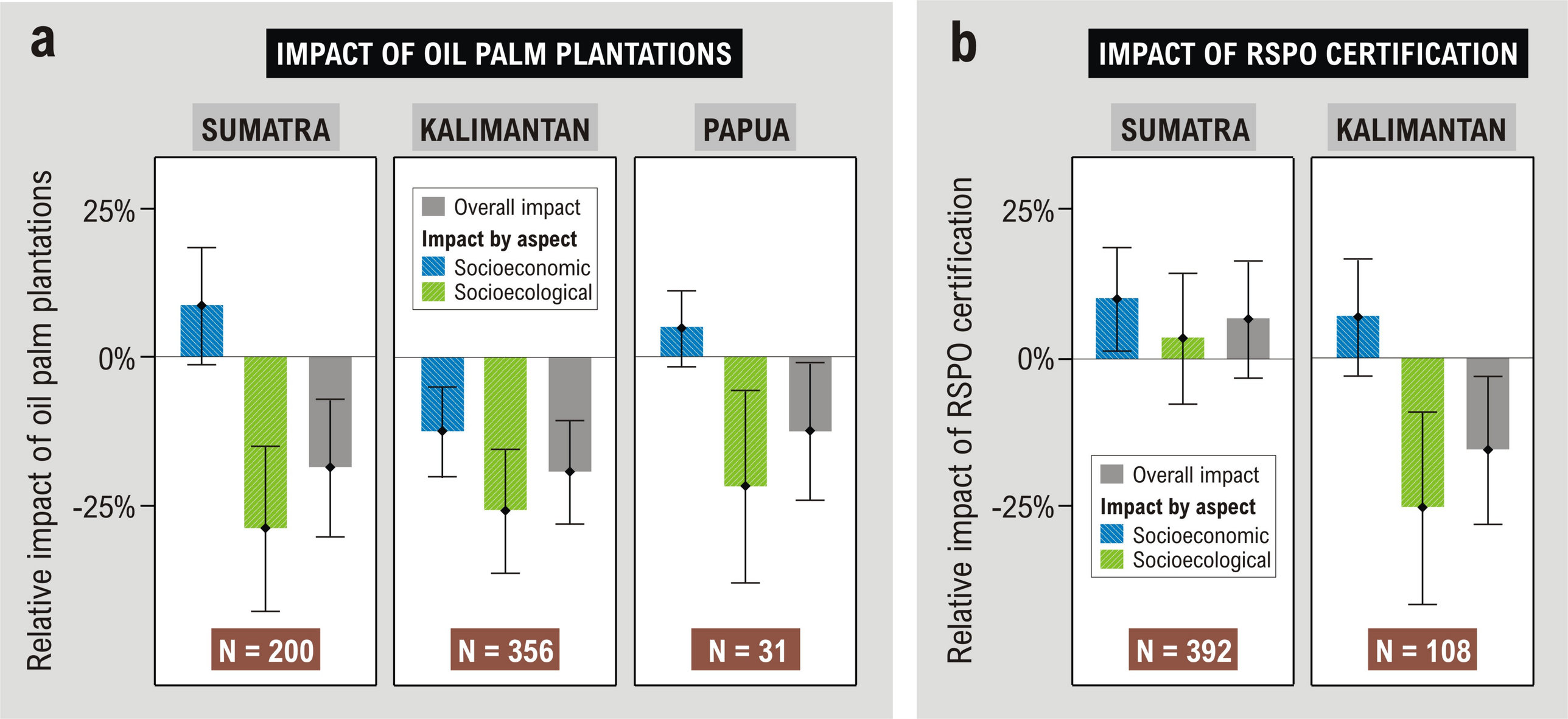
Relative impact of oil palm plantations

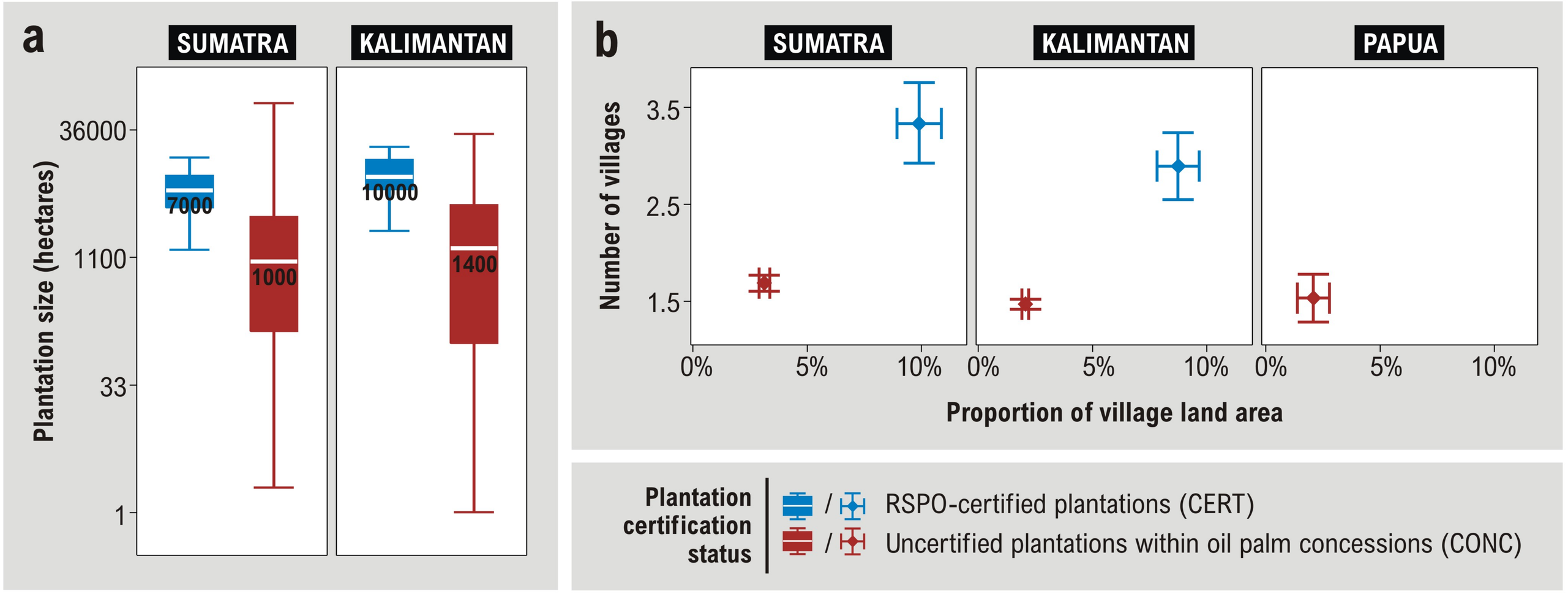
0.50
0.25
0.00
-0.25
-0.50
-0.75

N = 325

Well-being indicator

POOR ELCT COOK TOLT MLNT HEAL PSCH SSCH COOP CRDT | CNFL AGLB SIND SUIC GTRY WPOL APOL FLOD


a
IMPACT OF OIL PALM PLANTATIONS
SUMATRA
KALIMANTAN
PAPUA
Relative impact of oil palm plantations
25%
0%
-25%
Overall impact
Impact by aspect
Socioeconomic
Socioecological
N = 200
N = 356
N = 31
b
IMPACT OF RSPO CERTIFICATION
SUMATRA
KALIMANTAN
Relative impact of RSPO certification
25%
0%
-25%
Overall impact
Impact by aspect
Socioeconomic
Socioecological
N = 392
N = 108


a
SUMATRA
KALIMANTAN
Plantation size (hectares)
36000
1100
33
1
7000
1000
10000
1400
b
SUMATRA
KALIMANTAN
PAPUA
Number of villages
3.5
2.5
1.5
0%
5%
10%
Proportion of village land area
Plantation certification status
RSPO-certified plantations (CERT)
Uncertified plantations within oil palm concessions (CONC)